PB91-102145

Assessment of Risks from Exposure of Humans, Terrestrial and Avian Wildlife, and Aquatic Life to Dioxins and Furans from Disposal and Use of Sludge from Bleached Kraft and Sulfite Pulp and Paper Mills

Abt Associates, Inc., Cambridge, MA

Prepared for:

Environmental Protection Agency, Washington, DC

Jul 90

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. EPA 560/5-90-013

2.

3. PB91-102145

4. Title and Subtitle Assessment of Risks from Exposure of Humans, Terrestrial and Avian Wildlife, and Aquatic Life to Dioxins and Furans from Disposal and Use of Sludge from Bleached Kraft and Sulfite Pulp and Paper Mills

5. Report Date 7/90

6.

7. Author(s) Kirk O'Neal, Susan Keane, Randi Zielinski, Pat Jennings, Priscilla Halloran, Greg Schweer, Bob Morcock, Bill Rabert

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Abt Associates, Inc.
55 Wheeler St.
Cambridge, MA 02138

10. Project/Task/Work Unit No. 3-02, 1-15

11. Contract(C) or Grant(G) No.
(C) EPA 68-02-4283
(G) EPA 68-D9-0169

12. Sponsoring Organization Name and Address

United States Environmental Protection Agency
Office of Toxic Substances and Office of Solid Waste
401 M St., SW
Washington, D.C. 20460

13. Type of Report & Period Covered Final Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report assesses potential risks from exposure of humans, terrestrial and avian wildlife, and aquatic life to dioxins and furans from disposal and use of sludge from bleached kraft and sulfite pulp and paper mills. Potential risks to humans as a result of disposal of bleached paper wastes were also assessed. Pulp and paper mill sludge management practices for which general population risks were assessed include landfilling, surface impoundment, land application and distribution and marketing.

Effects on terrestrial and avian wildlife were examined as a result of land application of pulp and paper mill sludge. Pathways of exposure considered for wildlife include direct ingestion of soil and ingestion of prey items that have bio-concentrated dioxins and furans. Effects on aquatic life from discharge of pulp and paper mill effluents were also addressed.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement Distribution unlimited

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

21. No. of Pages

22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

United States
Environmental Protection
Agency

Office of Toxic Substances
Office of Solid Waste
TS-792, OSW-300

EPA 560/5-90-013
July 1990

PB91-102145

EPA

Assessment of Risks from Exposure of Humans, Terrestrial and Avian Wildlife, and Aquatic Life to Dioxins and Furans from Disposal and Use of Sludge from Bleached Kraft and Sulfite Pulp and Paper Mills

Printed on Recycled Paper

REPRODUCED BY
U.S. DEPARTMENT OF COMMERCE
NATIONAL TECHNICAL
INFORMATION SERVICE
SPRINGFIELD, VA 22161

EPA 560/5-90-013
July 1990

ASSESSMENT OF RISKS FROM EXPOSURE OF HUMANS, TERRESTRIAL AND AVIAN WILDLIFE, AND AQUATIC LIFE TO DIOXINS AND FURANS FROM DISPOSAL AND USE OF SLUDGE FROM BLEACHED KRAFT AND SULFITE PULP AND PAPER MILLS

by

Kirk O'Neal, Susan Keane, Randi Zielinski,
Pat Jennings, Priscilla Halloran, Greg Schweer,
Bob Morcock, Bill Rabert

EPA Contract Nos. 68-02-4283 and 68-D9-0169

U.S. ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF PESTICIDES AND TOXIC SUBSTANCES,
OFFICE OF TOXIC SUBSTANCES,
OFFICE OF SOLID WASTE AND EMERGENCY RESPONSE,
OFFICE OF SOLID WASTE
WASHINGTON, D.C. 20460

DISCLAIMER

This document has been reviewed and approved for publication by the Office of Toxic Substances, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency. The use of trade names or commercial products does not constitute Agency endorsement or recommendation for use.

ACKNOWLEDGEMENTS

This report was prepared by Abt Associates Inc. of Cambridge, Massachusetts for the EPA Office of Toxic Substances and the EPA Office of Solid Waste under EPA Contract No. 68-02-4283, Task 3-02, and EPA Contract No. 68-D9-0169, Task 1-15. Pat Jennings and Greg Schweer served as Task Managers for the Office of Toxic Substances. Priscilla Halloran served as Task Manager for the Office of Solid Waste. Bob Morcock of the Office of Toxic Substances provided guidance in estimating wildlife effects. Annett Nold of the Office of Toxic Substances provided guidance in modeling releases from landfills to ground water and air. Acknowledgement is also given to Alec McBride of the Office of Solid Waste and Al Rubin of the Office of Water Regulations and Standards, who provided valuable comments on this report.

A number of Abt personnel have contributed to this task over the period of performance, as shown below:

Program Management - Mike Conti

Task Management - Kirk O'Neal
Susan Keane

Technical Support - Kathleen Bell
Brad Firlie
Caty McGuckin
Jeremy Wilson

Secretarial/Clerical - Paulette Gillard

TABLE OF CONTENTS

EXECUTIVE SUMMARY xi

1.0 INTRODUCTION 1

2.0 ESTIMATES OF EXPOSURE AND RISKS TO HUMANS FROM CURRENT DISPOSAL/REUSE PRACTICES 13

2.1 EXPOSURE AND RISKS FROM DISPOSAL OF PULP AND PAPER SLUDGE IN LANDFILLS 15
- 2.1.1 Estimates of Exposure and Risks from Inhalation of Vapors 24
- 2.1.2 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 31
- 2.1.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 48
- 2.1.4 Estimates of Exposure and Risks from Ingestion of Fish 60
- 2.1.5 Summary of Results 65

2.2 EXPOSURE AND RISKS FROM DISPOSAL OF PAPER PRODUCTS IN MUNICIPAL LANDFILLS 73
- 2.2.1 Estimates of Exposure and Risks from Inhalation of Vapors 75
- 2.2.2 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 79
- 2.2.3 Summary of Results 82

2.3 EXPOSURE AND RISKS FROM DISPOSAL OF PULP AND PAPER SLUDGE IN SURFACE IMPOUNDMENTS 89
- 2.3.1 Estimates of Exposure and Risks from Inhalation of Vapors 89
- 2.3.2 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 105
- 2.3.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 116
- 2.3.4 Estimates of Exposure and Risks from Ingestion of Fish 128
- 2.3.5 Summary of Results 132

2.4 EXPOSURE AND RISKS FROM LAND APPLICATION OF PULP AND PAPER SLUDGE 137
- 2.4.1 Estimates of Exposure and Risks from Dermal Contact with Sludge 146
- 2.4.2 Estimates of Exposure and Risks from Ingestion of Produce, Meat, and Dairy Products Grown on Sludge-Amended Land 163
- 2.4.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge 193
- 2.4.4 Estimates of Exposure and Risks from Inhalation of Sludge Particulates 203
- 2.4.5 Estimates of Exposure and Risks from Inhalation of Vapors 220
- 2.4.6 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 223
- 2.4.7 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 228

2.4.8 Estimates of Exposure and Risks from Ingestion of Fish 242
2.4.9 Summary of Results 246

2.5 EXPOSURE AND RISKS FROM DISTRIBUTION AND MARKETING OF PULP AND PAPER SLUDGE 253
2.5.1 Estimates of Exposure and Risks from Dermal Contact with Sludge 264
2.5.2 Estimates of Exposure and Risks from Ingestion of Home-Grown Produce 281
2.5.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge 291
2.5.4 Estimates of Exposure and Risks from Inhalation of Sludge Particulates 301
2.5.5 Estimates of Exposure and Risks from Inhalation of Vapors 319
2.5.6 Summary of Results 322

3.0 ESTIMATES OF EXPOSURE AND RISKS TO WILDLIFE FROM LAND APPLICATION OF PULP AND PAPER SLUDGE 329

3.1 DEVELOPMENT OF TOXICITY MEASURES TO WHICH WILDLIFE EXPOSURES ARE COMPARED 330

3.2 METHODS FOR ESTIMATING EXPOSURES TO WILDLIFE 336

3.3 SUMMARY OF RESULTS 355

3.4 COMPARISON OF WILDLIFE RISK MODEL TO RESULTS OF FIELD STUDIES 360

4.0 ANALYSIS OF UNCERTAINTY 367

5.0 CONCLUSIONS ON THE ANALYSIS OF CURRENT PRACTICES 403

6.0 ESTIMATES OF EXPOSURE AND RISKS TO HUMANS BASED ON GENERIC DISPOSAL/REUSE SCENARIOS 427

6.1 EXPOSURE AND RISKS FROM DISPOSAL OF PULP AND PAPER SLUDGE IN LANDFILLS 429
6.1.1 Estimates of Exposure and Risks from Inhalation of Vapors 434
6.1.2 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 434
6.1.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 440
6.1.4 Estimates of Exposure and Risks from Ingestion of Fish 444
6.1.5 Summary of Results 445

6.2 EXPOSURE AND RISKS FROM DISPOSAL OF PULP AND PAPER SLUDGE IN SURFACE IMPOUNDMENTS 445
6.2.1 Estimates of Exposure and Risks from Inhalation of Vapors 448
6.2.2 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources 452
6.2.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 457

6.2.4 Estimates of Exposure and Risks from Ingestion of Fish 461
6.2.5 Summary of Results 462

6.3 EXPOSURE AND RISKS FROM LAND APPLICATION OF PULP AND PAPER SLUDGE 465
6.3.1 Estimates of Exposure and Risks from Dermal Contact with Sludge 470
6.3.2 Estimates of Exposure and Risks from Ingestion of Produce, Meat, and Dairy Products Grown on Sludge-Amended Land 475
6.3.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge 483
6.3.4 Estimates of Exposure and Risks from Inhalation of Sludge Particulates 485
6.3.5 Estimates of Exposure and Risks from Inhalation of Vapors 486
6.3.6 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources 490
6.3.7 Estimates of Exposure and Risks from Ingestion of Fish 498
6.3.8 Summary of Results 499

6.4 EXPOSURE AND RISKS FROM DISTRIBUTION AND MARKETING OF PULP AND PAPER SLUDGE 504
6.4.1 Estimates of Exposure and Risks from Dermal Contact with Sludge 505
6.4.2 Estimates of Exposure and Risks from Ingestion of Home-Grown Produce 514
6.4.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge 516
6.4.4 Estimates of Exposure and Risks from Inhalation of Sludge Particulates 518
6.4.5 Estimates of Exposure and Risks from Inhalation of Vapors 519
6.4.6 Summary of Results 523

6.5 CONCLUSIONS 526
6.5.1 Discussion of Results 526
6.5.2 Comparison with Site Specific Assessment 526

APPENDIX A: METHODS FOR ESTIMATING SOIL CONCENTRATIONS 537

APPENDIX B: METHODS FOR ESTIMATING CONTAMINANT CONCENTRATIONS IN SURFACE WATER AND FISH 541

APPENDIX C: COMPARISON OF TWO METHODS FOR ESTIMATING SEDIMENT AND WATER CONTAMINANT CONCENTRATIONS RESULTING FROM CONTAMINATED SOIL EROSION FROM SLUDGE MANAGEMENT AREAS 551

APPENDIX D: EXPOSURE ESTIMATES FOR WILDLIFE 555

APPENDIX E: SAMPLE CALCULATIONS 603

APPENDIX F: UPDATE TO ECOLOGICAL RISK ASSESSMENT 647

Executive Summary

Purpose and Scope of this Analysis

The U.S. Environmental Protection Agency (EPA) has undertaken a comprehensive assessment of potential human and environmental exposure to polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) associated with the U.S. pulp and paper industry. One potential source of exposure to these contaminants is the sludge generated by that industry; sludge from pulp and paper plants that use chlorine are known to contain measurable quantities of PCDDs and PCDFs. EPA estimates that approximately 2.5 million metric tons of such sludge is generated annually. Most is landfilled or placed in surface impoundments; the remainder is incinerated, land-applied, or distributed and marketed. Each of these five use or disposal practices presents potential risks of ecological or human health impacts resulting from exposure to dioxins in the sludge.

A second potential source of exposure is the disposal of paper wastes. EPA estimates that about 45 million metric tons of pulp and paper products are disposed annually. When discarded paper products are buried in municipal landfills or burned in municipal incinerators, PCDDs and PCDFs may be released into the environment, resulting in potential exposure to humans or wildlife.

The purpose of this study is to estimate potential human and wildlife exposure to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF)[1] from the use or disposal of pulp and paper sludge and from the disposal of pulp and paper products. This analysis estimates risks from (1) generic disposal and use scenarios and (2) the current pattern of use and disposal. The generic assessment uses generalized, worst case estimates for model parameters describing contaminant concentrations and site characteristics, while the analysis of current practices uses site-specific data on existing sludge use and disposal practices to provide an estimate of risk under current conditions. The generic assessment allows identification of those practices that are intrinsically risky and is independent of the particular pattern of current sludge use and disposal, which is subject to change over time. The generic assessment is more appropriate for use in regulatory and management decision-making.

---

[1] Throughout this report, "TCDD" will refer to 2,3,7,8-tetrachlordibenzo-p-dioxin, and "TCDF" will refer to 2,3,7,8-tetrachlorodibenzofuran.

Both the generic assessment and the analysis of current practices consider four waste disposal practices:

- Landfilling of pulp and paper sludge,
- Surface impoundment of pulp and paper sludge,
- Land application of pulp and paper sludge, and
- Distribution and marketing of pulp and paper sludge.

Landfilling of paper contaminated with dioxin is also considered in the analysis of current practices. Risks from incineration of waste paper products, and from incineration of pulp and paper sludge, have been examined by a separate analysis, and are not discussed in this report. Table A lists the quantities of wastes currently used or disposed of by each of these waste management practices. These quantities were used in the analysis of current practices. As can be seen from the table, landfills and surface impoundments receive most of the sludge generated each year. Lesser amounts are land-applied or distributed and marketed. Short descriptions of each waste management practice are provided below.

Description of Waste Management Practices

Landfilling of sludge from the pulp and paper industry is defined as the burial of sludge on land. Once a landfill's capacity is exhausted, a permanent cover of soil, clay or other material may be applied to the site. Sludge landfills can be loosely categorized into two groups: industrial landfills that receive only wastes from the pulp and paper industry, and municipal landfills that accept the pulp and paper sludge as part of a broader waste stream. Of the fifty-nine pulp and paper mills that report disposal of sludge in landfills, at least 15 use municipal facilities. Risk estimates presented for current practices, however, are based on hypothetical scenarios involving the disposal of sludge in industrial landfills only. Estimates for industrial facilities have been generalized to describe exposure and risks from disposal of sludge in municipal landfills. To the extent that conditions differ in municipal facilities, risk estimates generated by this analysis may over- or under-estimate actual risks for these facilities.

The analysis of current practices estimates potential groundwater and volatilization risks from the landfill disposal of TCDD- and TCDF-contaminated paper products. Because preliminary, upper bound estimates of expesure and risks through these two pathways yielded low risk estimates, estimates of potential exposure and risk have not been prepared for the generic analysis.

Table A. Use and Disposal Methods for Pulp and Paper Mill Sludge

	Number of Mills	Quantity of sludge received[a] (dry tons/yr)	Percent of total
Landfill	59	1,100,000	44
Surface Impoundment	20	600,000	24
Land Application	7	300,000	12
Incineration[b]	19	300,000	12
Distr. and Marketing	7	200,000	8
Total	104[c]	2,500,000	100

Notes:

[a] Where plants report multiple sludge re-use or disposal methods, reported quantities have been divided among relevant categories.

[b] Not considered in this analysis.

[c] Some plants use more than one sludge re-use or disposal method.

Surface impoundments are defined as facilities in which pulp and paper mill sludges are stored or disposed on land without a cover layer of soil. It is assumed that sludge contained in such facilities has a higher moisture content than the sludge deposited in landfills, at least during the active phase of the facility's lifetime.

Land application of pulp and paper sludge, in addition to serving as a method of sludge disposal, also fertilizes and conditions soil. Pulp and paper mill sludge may also be composted with other materials and then distributed and marketed as a soil amendment. The product is then used for residential gardening and lawn care, or for agricultural and commercial purposes. This analysis examines risks from the residential uses of distributed and marketed sludge. Since the actual users of the composted sludge are not known, a hypothetical scenario is used in the generic and in the current practice analyses to estimate potential human exposure to TCDD and TCDF through this practice.

Exposure Pathways Considered

For each of the waste management practices described above, humans and wildlife can be exposed to potential health risks if TCDD and TCDF are released into the environment and come into contact with wildlife or humans. Such contact is possible through a variety of possible exposure pathways, including the following, which are considered in this analysis:

- TCDD and TCDF migrate from sludge or landfilled paper to an aquifer underneath the disposal site or land application site. Humans withdraw drinking water from the aquifer and are exposed.
- TCDD or TCDF from sludge or landfilled paper volatilizes and escapes into the atmosphere. Humans inhale the contaminated air and are exposed.
- Particles of treated soil or sludge become suspended in air. Humans inhale the particles and are exposed to adsorbed TCDD and TCDF.
- TCDD or TCDF from sludge or treated soil are carried by surface runoff to a nearby lake or stream. Humans withdraw drinking water from the contaminated lake or stream and are exposed.
- TCDD or TCDF from sludge or treated soil are carried by surface runoff to a nearby lake or stream. Fish living in the contaminated water take up the contaminants into their tissues. Humans consume the fish and are exposed.
- Soil treated with sludge is used to grow produce for human consumption, or feed for animals. TCDD and TCDF enter the soil, and are taken up into the tissues of crops grown on the treated land. Humans consume the produce or consume the meat and dairy products produced from the feed, and are exposed.
- Human skin comes into contact with soil that has been treated with sludge. Humans are exposed when TCDD and TCDF from the soil are absorbed by the skin.

- Children and adults ingest small quantities of sludge or treated soil, and are exposed.
- Wildlife feed in areas treated with pulp and paper sludge. They ingest soil and food items contaminated with TCDD and TCDF, and are exposed.

Table B summarizes the pathways of potential human or wildlife exposure considered for each waste disposal practice. As can be seen from the table, all of the eight exposure pathways have been considered when estimating risks from land application. Fewer pathways were thought to present significant risks for other waste management practices.

Key Assumptions Used in Analysis

The analysis of current practices and the generic analysis both use mathematical models to estimate the extent to which humans and wildlife are exposed to TCDD and TCDF from pulp and paper mill sludge or from landfilled paper wastes. For each waste use or disposal method and for each pathway of potential exposure, the analysis begins by estimating concentrations of TCDD and TCDF in the environmental medium or media of concern. Results are then combined with assumptions about human or wildlife behavior to estimate expected exposure and risk. For each exposure pathway, this analysis prepares separate exposure and risk estimates for a "most exposed individual" (MEI) and for the total exposed population.

As with any modeling effort, the precision of the resulting estimates is a function of the suitability of the mathematical models chosen for the calculations, and of the quality of the assumptions and input parameters used. Assumptions and input parameters used for estimating exposure and risk are described in detail throughout this report. Some of the more fundamental assumptions involved in this analysis are listed below:

- For the analysis of current practices, data from the 104-Mill Study provide an accurate description of current sludge production, contaminant concentrations, and use and disposal methods.
- Assumptions regarding management practices (use of liners for landfills, berms for surface impoundments, etc.) are representative of current practices, or of worst case scenarios, where appropriate.
- Assumptions regarding facility siting (distance to surface water, distance to human populations, etc.) are realistic.
- Assumptions regarding human behavior (both typical and worst case) are realistic.
- Selected mathematical models provide reasonable predictions of the fate and transport of TCDD and TCDF in environmental media.

Table B. Exposure Pathways Evaluated for Each Waste Use or Disposal Practice

Exposure pathway	Sludge landfill	Sludge Paper landfill	Sludge surface impoundment	Sludge land application	Sludge distribution & marketing
Human exposure					
Ingestion exposure from drinking contaminated groundwater:	●	●	●	●	
Ingestion exposure from drinking surface water contaminated by runoff:	●		●	●	
Ingestion exposure from foods produced with contaminated soil:				●	●
Ingestion exposure from consumption of fish caught in contaminated surface water:	●		●	●	
Ingestion exposure from direct ingestion of contaminated soil:				●	●
Inhalation exposure to volatilised contaminants:	●	●	●	●	●
Inhalation exposure to particulates from contaminated soil:				●	●
Dermal exposure from contact with contaminated soil:				●	●
Wildlife exposure					
Ingestion exposure from ingestion of contaminated food items:				●	

Where significant uncertainties or data gaps exist, this analysis attempts to quantify the range of possible error in its exposure and risk estimates. An analysis of the uncertainty in the assessment of current practices is provided in Section 4.0 of this report.

Summary of Results of Generic Assessment

Table C presents the maximum risk associated with each disposal or use method in the generic assessment. These tables show that the greatest MEI risks from landfills, surface impoundments, and land application are of a similar magnitude. The four disposal or use methods considered yield very similar total population risks, differing by less than a factor of three. The greatest typical individual risk is a result of inhalation of TCDD and TCDF that volatilized from sludge applied agriculturally. Volatilized TCDD and TCDF from land applied sludge presents risks that are almost two orders of magnitude greater than highest typical individual risk resulting from other sludge disposal methods.

Tables D through G provide a more detailed listing of estimated human exposure to TCDD and TCDF from each waste management method and exposure pathway. As can be seen from Table D, risks to the "most exposed individual" from the landfilling of sludge are highest from pathways associated with ingestion of fish contaminated by surface runoff. Estimated risks through these pathways for the MEI are based on a scenario in which runoff from the site reaches a stream of relatively small drainage area; typical individual risks through surface water pathways are estimated based on larger assumed drainage areas, and are considerably lower.

Estimated risks from disposal of sludge in surface impoundments are presented in Table E. As with landfills, estimated risks from this sludge storage or disposal practice are dominated by pathways associated with surface runoff. These estimates are based on the assumption that the most exposed individual takes drinking water and fish from a relatively small stream and from the stream location with maximum dissolved concentrations of TCDD and TCDF.

Estimated risks from inhalation of volatilized contaminants from a surface impoundment are higher than those estimated for landfills, since rates of contaminant emissions from an uncovered liquid impoundment surface are estimated to be higher than those estimated from a landfill with soil cover. As with landfills, TCDF dominates risks through the volatilization pathway, because of its higher mobility. Estimated typical risks to exposed individuals are significantly lower than those estimated for the "most exposed individual."

Table F shows estimated human health risks associated with the eight human exposure pathways evaluated for the land application of pulp and paper sludge. Highest MEI health risks

Table C. Maximum Human Health Risks from Exposure to TCDD and TCDF, by Waste Management Method

Exposure Pathway	MEI risk[a,b] (per lifetime)	Typical risk[a,c] (per lifetime)	Exposed population[d]	Total risk (cases/year)[e]
Potential human exposure from disposal of pulp and paper sludge in landfills (percent TCDD)[f]	5×10^{-2} (63)	8×10^{-8} (65)	14,200,000	2×10^{-2} (65)
Potential human exposure from disposal of pulp and paper sludge in surface impoundments (percent TCDD)[f]	1×10^{-1} (63)	1×10^{-7} (65)	4,760,000	7×10^{-3} (65)
Human exposure from land application of pulp and paper sludge (percent TCDD)[f]	2×10^{-1} (63)	1×10^{-5} (4)	1,700,000	1×10^{-2} (65)
Human exposure from distribution and marketing of pulp and paper sludge (percent TCDD)[f]	1×10^{-4} (63)	3×10^{-7} (56)	3,500,000	1×10^{-2} (56)

Notes:

[a] Calculated as: [Estimated Exposure, in mg/kg/day] $\times 1.5 \times 10^{5}$ $(\text{mg/kg/day})^{-1}$

[b] Represents highest risk to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method.

[c] Represents highest risk to typical exposed individual for any single exposure pathway for this disposal or reuse method.

[d] Total exposed population for single exposure pathway associated with highest total risks for this sludge re-use or disposal method. Does not necessarily correspond to size of population exposed to highest typical individual risk.

[e] Calculated as: [Typical Risk for the pathway x Exposed Population for the pathway] / [Life Expectancy]

[f] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table D. Human Health Risk Estimates from Landfill Disposal
of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed: (Percent TCDD)[c]	4×10^{-7} (4.03)	1×10^{-9} (4.44)	12,800,000	2×10^{-4} (4.44)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed: (Percent TCDD)[c]	1×10^{-9} (2)	1×10^{-10} (8)	19,000	3×10^{-8} (8)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	7×10^{-4} (0.6)	5×10^{-8} (0.6)	6,980,000	5×10^{-3} (0.6)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	5×10^{-2} (63)	8×10^{-8} (65)	14,200,000	2×10^{-2} (65)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \dfrac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table E. Human Health Risk Estimates from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	1×10^{-6} (0.6)	4×10^{-8} (0.7)	7,100,000	4×10^{-3} (0.7)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-8} (0.4)	5×10^{-10} (0.7)	6,000	4×10^{-8} (0.7)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-3} (0.6)	7×10^{-8} (0.7)	2,330,000	2×10^{-3} (0.7)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	1×10^{-1} (63)	1×10^{-7} (65)	4,760,000	7×10^{-3} (65)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table F. Human Health Risk Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-5} (62)	3×10^{-7} (65)	40	2×10^{-7} (65)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-5} (62)	1×10^{-6} (65)	40	7×10^{-7} (65)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (4)	1×10^{-5} (4)	40	7×10^{-6} (4)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-6} (62)	7×10^{-7} (65)	40	4×10^{-7} (65)
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by agricultural land application of sludge: (Percent TCDD)[c]	2×10^{-3} (0.6)	3×10^{-7} (0.6)	333,000	1×10^{-3} (0.6)

Table F. (con't.). Human Health Risk Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge to mines/forests: (Percent TCDD)[c]	3×10^{-3} (0.6)	3×10^{-7} (0.6)	833,000	4×10^{-3} (0.6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c]	$<6 \times 10^{-7}$ (0.2)	$<6 \times 10^{-7}$ (0.2)	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by agricultural land application of sludge: (Percent TCDD)[c]	1×10^{-1} (63)	5×10^{-7} (65)	679,000	4×10^{-3} (65)
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by application of sludge to mines/forests: (Percent TCDD)[c]	2×10^{-1} (63)	5×10^{-7} (65)	1,700,000	1×10^{-2} (65)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-2} (62)	2×10^{-10} (65)	240,000,000	7×10^{-4} (65)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

[d] Not applicable.

Table 6. Human Health Risk Estimates from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-4} (63)	3×10^{-8} (59)	3,500,000	1×10^{-3} (59)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-4} (57)	3×10^{-7} (56)	3,500,000	1×10^{-2} (56)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	6×10^{-7} (5)	4×10^{-9} (6)	3,500,000	2×10^{-3} (6)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-7} (64)	4×10^{-9} (71)	3,500,000	2×10^{-4} (71)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-8} (62)	4×10^{-11} (71)	3,500,000	2×10^{-6} (71)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

from land application are encountered through the fish ingestion pathway. After the fish ingestion exposure pathway, the next highest risk estimates for the MEI are found for the dietary pathway.

Risks to typical exposed individuals are low through all exposure pathways analyzed for land application; highest typical risks are estimated for persons living near a land application site and inhaling TCDD and TCDF vapor emitted by treated soil. Highest total population risks are estimated for the fish ingestion pathway.

Estimated risks from the distribution and marketing of pulp and paper sludge are based on the assumption that all of the sludge is used for vegetable or ornamental gardening in residential settings. As shown in Table G, estimated risks to the "most exposed individual" are lowest for inhalation and dietary pathways, and highest for pathways involving direct human contact with sludge or soil. Risks to gardening individuals with more "typical" behaviors are two to four orders of magnitude lower than those estimated for the MEI.

Summary of Results of Analysis of Current Practices: Human Exposure and Health Risks

Tables H and I present the maximum exposure and risk associated with each disposal or use method in the analysis of current practices. Table H compares exposure estimates for each waste disposal method analyzed, while Table I shows the corresponding risk estimates. For each waste management practice, the tables report results for the exposure pathway found to result in highest risks to the "most exposed individual" and to the total population. It ignores the possibility of simultaneous exposure through multiple pathways. By comparing maximum estimated risks for each management practice, the table allows a simple comparison of risks associated with each practice.

As can be seen from Table I, estimated risks to the "most exposed individual" are lowest for the landfilling of paper wastes, and highest for sludge surface impoundments and land application. Total risks to an exposed population are highest for land application. Estimated risks to typical exposed individuals are four to five orders of magnitude lower than risks to the MEI, except for the landfilling of paper wastes, for which separate population risk estimates were not performed. The largest exposed population is associated with the land application of sludge, since foods grown with sludge-amended land may enter national food distribution systems and be consumed by the entire U.S. population. As shown by the table, none of the waste disposal methods and exposure pathways analyzed is expected to result in total risks of more than one incremental cancer case per twenty years of sludge or paper disposal.

Table N. Maximum Exposure to TCDD and TCDF by Waste Use or Disposal Method

Exposure Pathway	MEI Exposure^{a,b} (mg/kg/day)	(% TCDD)^{c}	Typical Exposure^{a,d} (mg/kg/day)	(% TCDD)^{c}
Potential Human Exposure from Disposal of Pulp and Paper Sludge in Landfills	6×10^{-9}	(22)	2×10^{-13}	(0.4)
Potential Human Exposure from Disposal of Paper Wastes in Landfills	1×10^{-15}	(50)	1×10^{-15}	(50)
Potential Human Exposure from Disposal of Pulp and Paper Sludge in Surface Impoundments	7×10^{-8}	(59)	1×10^{-12}	(0.8)
Human Exposure from Land Application of Pulp and Paper Sludge	7×10^{-8}	(>99)	2×10^{-13}	(6)
Human Exposure from Distribution and Marketing of Pulp and Paper Sludge	8×10^{-10}	(35)	2×10^{-13}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + one tenth of estimated exposure to 2,3,7,8-TCDF.

[b] Represents highest exposure to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method. All exposure estimates based on "best estimate" input parameters.

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

[d] Represents highest average exposure through any single exposure pathway associated with this waste disposal or re-use method. All exposure estimates based on "best estimate" input parameters.

Table I. Maximum Human Health Risks from Exposure to TCDD and TCDF, by Waste Management Method

Exposure Pathway	MEI risk[a,b] (per lifetime)	Typical risk[a,c] (per lifetime)	Exposed population[d]	Total risk (cases/year)[e]
Potential human exposure from disposal of pulp and paper sludge in landfills (percent TCDD)[f]	2×10^{-3} (0.2)	5×10^{-8} (0.4)	6,982,000	5×10^{-3} (0.4)
Potential human exposure from disposal of paper wastes in landfills (percent TCDD)[f]	$<3 \times 10^{-10}$ (50)	not estimated	not estimated	not estimated
Potential human exposure from disposal of pulp and paper sludge in surface impoundments (percent TCDD)[f]	2×10^{-2} (59)	3×10^{-7} (0.8)	7,100,000	2×10^{-2} (0.8)
Human exposure from land application of pulp and paper sludge (percent TCDD)[f]	2×10^{-2} (>99)	7×10^{-6} (>99)	240,000,000	7×10^{-2} (>99)
Human exposure from distribution and marketing of pulp and paper sludge (percent TCDD)[f]	2×10^{-4} (98)	6×10^{-8} (38)	3,500,000	3×10^{-3} (2)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Represents highest risk to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method. All risk estimates based on "best estimate" input parameters.

[c] Represents risk to average exposed individual for single exposure pathway associated with highest total risk for this waste disposal or re-use method. All risk estimates based on "best estimate" input parameters.

[d] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[e] Total exposed population for single exposure pathway associated with highest total risks for this sludge re-use or disposal method.

[f] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$

Table J reports estimated human health risks from the disposal of paper wastes in municipal landfills. Estimates reported in the Table for the MEI are based on consistently conservative assumptions chosen to provide upper-bound risk estimates. TCDF is more easily volatilized from landfills than TCDD, and is responsible for most of the estimated risk through the volatilization pathway.

Summary of Results of Analysis of Current Practices: Risks to Wildlife

Risks to wildlife were assessed for the land application of sludge. Wildlife risks were estimate only in the analysis of current practices, and were therefore based on model assumptions consistent with the current practice analysis. Tables K through M summarize results. Table K presents a summary of risks to birds foraging from land application sites. This table shows the lowest and highest estimates of the daily dose (expressed as a percent of the "no observable adverse effects level" or NOAEL) among the seven land application sites assessed in this analysis. Similarly, Table L summarizes the risks to bird eggs, while Table M presents the risks to mammalian species. These results show that those species whose diets consist largely of prey species that bioconcentrate TCDD and TCDF are at greatest risk from the land application of sludges containing TCDD and TCDF.

The wildlife risk assessment results imply that individual members of certain wildlife species are at risk for reproductive and other effects from the land application of pulp and paper mill sludges containing TCDD and TCDF. Adverse effects on individuals may be important if the individuals affected are members of species that are endangered or threatened. In Maryland, the loggerhead shrike ingests a daily dose that is almost three times the NOAEL for nonmigratory birds. Furthermore, the eggs of this species have a TCDD concentration that is almost four times the TCDD "lowest observable adverse effect level" (or LOAEL) for eggs. The loggerhead shrike is considered a threatened species in that state.

This assessment does not attempt to quantify the effects of TCDD and TCDF on populations or ecosystems. However, the results of the assessment show that at certain land application sites, the reproductive capability of individuals of certain species may be affected. Effects on the reproductive capability of a sufficient number of individual members of a species may lead to overall population effects for that species in that area.

Table J. Best Estimate of Human Health Risk from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<9 \times 10^{-7}$ (16)	$<9 \times 10^{-7}$ (16)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<2 \times 10^{-9}$ (53)	$<2 \times 10^{-9}$ (53)	18,500,000	$<4 \times 10^{-4}$ (53)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

Table K. Summary of Risks to Birds ("Best Estimate")

Species	Lowest Value for Dose as a Percent of NOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of NOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	0	0	PA	309	169	OH
American Robin	1	0	PA, MS (TCDF)	413	114	GA
Great Crested Flycatcher	0	0	PA, MS (TCDF)	328	91	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	520	285	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	160	88	OH
Tree Swallow	2	1	ME	334	92	GA
Pine Warbler	3	1	ME	476	132	GA
Woodcock	15	8	ME	2761	764	GA
Woodthrush	1	1	ME	194	54	GA

Table L. Summary of Risks to Bird Eggs ("Best Estimate")

Species	Lowest Value for Concentration as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Concentration as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	1	0	PA	675	55	OH
American Robin	1	0	PA, MS (TCDF)	1059	44	GA
Great Crested Flycatcher	1	0	PA, MS (TCDF)	624	26	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	720	49	OH
Eastern Meadowlark	1	0	PA, MS (TCDF)	382	31	OH
Tree Swallow	5	0	ME	818	34	GA
Pine Warbler	4	0	ME	679	28	GA
Woodcock	34	3	ME	6237	288	GA
Woodthrush	2	0	ME	405	17	GA

Table M. Summary of Risks to Mammals ("Best Estimate")

Species	Lowest Value for Dose as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Nine-banded Armadillo (1)	31	0	MS	31	0	MS
Grey Bat	2	0	PA, MS (TCDF)	1810	501	GA
Eastern Mole	2	0	PA, MS (TCDF)	1540	426	GA
River Otter	0	0	(2)	0	0	(2)
Virginia Opossum	0	0	PA, MS (TCDF)	288	80	GA
Least Shrew	6	0	PA, MS (TCDF)	4480	1240	GA
Striped Skunk	0	0	PA, MS (TCDF)	192	53	GA

(1) Armadillo only occurs in Mississippi

(2) River otter dose less than 0.5% in all states

1.0 Introduction

Background

The U.S. Environmental Protection Agency (EPA) is undertaking a comprehensive assessment of potential human and environmental exposure to polychlorinated dibenzodioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) associated with the U.S. pulp and paper industry. One potential source of exposure to these contaminants is the sludge generated by that industry; sludge from pulp and paper plants that use chlorine are known to contain measurable quantities of PCDDs and PCDFs. EPA estimates that approximately 2.5 million metric tons of such sludge is generated annually. Most is landfilled or placed in surface impoundments; the remainder is incinerated, land-applied, or distributed and marketed. Each of these five use or disposal practices presents potential risks of ecological or human health impacts resulting from exposure to dioxins in the sludge.

A second potential source of exposure is the disposal of paper wastes. EPA estimates that about 45 million metric tons of pulp and paper products are disposed annually. When discarded paper products are buried in municipal landfills or burned in municipal incinerators, PCDDs and PCDFs may be released into the environment, resulting in potential exposure to humans or wildlife.

Purpose and Scope of Analysis

The purpose of this study is to estimate potential exposure of humans and wildlife to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) and 2,3,7,8-tetrachlorodibenzofuran (TCDF)[1] from the use or disposal of pulp and paper sludge and from the disposal of pulp and paper products. Two separate analyses are performed. The "generic" analysis uses generalized, worst case estimates for model parameters describing contaminant concentrations and site characteristics. The other ("current practices") analysis uses site-specific data, where available, to provide an estimate of exposure and risks under current conditions. The generic assessment allows identification of those practices that are intrinsically risky, and is independent of the particular pattern of current sludge use and disposal, which is subject to change over time. It is therefore more appropriate for use in regulatory and management decision-making.

The work considers five waste disposal practices:

- Landfilling of pulp and paper sludge,

---

[1] For the remainder of this report, "TCDD" will refer to 2,3,7,8-dibenzo-p-dioxin, and "TCDF" will refer to 2,3,7,8-dibenzo-p-furan.

- Landfilling of paper wastes,
- Surface impoundment of pulp and paper sludge,
- Land application of pulp and paper sludge, and
- Distribution and marketing of pulp and paper sludge.

Table 1.A lists the quantities of wastes currently used or disposed of by each waste management practice. As can be seen from the table, most pulp and paper mills surveyed reported disposing of their sludge in landfills. About seventy percent of the 2.5 million tons of sludge produced annually is estimated to be received by landfills or surface impoundments. Lesser amounts are land-applied, incinerated, or distributed and marketed. Risks from incineration of waste paper products, and from incineration of pulp and paper sludge, have been examined by a separate analysis, and are not discussed in this report.

Description of Practices, Quantities and Concentrations

Landfilling of sludge from the pulp and paper industry is defined as the burial of sludge on land, usually accompanied by the regular application of soil cover. Once a landfill's capacity is exhausted, a permanent cover of soil, clay or other material may be applied to the site. Sludge landfills can be loosely categorized into two groups: industrial landfills that receive only wastes from the pulp and paper industry, and municipal landfills that accept pulp and paper sludge as part of a broader waste stream. For lack of information about management practices at industrial landfills for pulp and paper sludge, the generic analysis conservatively assumes that no permanent soil cover is applied. Similarly, estimates of expected runoff and volatilization for the current practices analysis are based on the assumed absence of soil cover.

Of the fifty-nine pulp and paper mills that report disposal of sludge in landfills, at least 15 use municipal facilities. Risk estimates presented in this report, however, are based on hypothetical scenarios involving the disposal of sludge in industrial landfills only. The average landfill is assumed to be approximately 12 hectares in size, with an average active life of 14 years and depth of six meters. Estimates for industrial facilities have been generalized to describe exposure and risks from disposal of sludge in municipal landfills. To the extent that conditions differ in municipal facilities, risk estimates generated by this analysis may over- or under-estimate actual risks for these facilities.

This analysis also evaluates potential risks from contamination of groundwater and ambient air through the disposal of TCDD- and TCDF-contaminated paper products in municipal landfills. Because preliminary, upper bound estimates of exposure and risks through these two pathways yielded low risk estimates, estimates of potential exposure and risk under more typical conditions

Table 1.A. Use and Disposal Methods for Pulp and Paper Mill Sludge

	Number of Mills	Quantity of sludge received[a] (dry tons/yr)	Percent of total
Landfill	59	1,100,000	44
Surface Impoundment	20	600,000	24
Land Application	7	300,000	12
Incineration[b]	19	300,000	12
Distr. and Marketing	7	200,000	8
Total	104[c]	2,500,000	100

Notes:

[a] Where plants report multiple sludge re-use or disposal methods, reported quantities have been divided among relevant categories.

[b] Not considered in this analysis.

[c] Some plants use more than one sludge re-use or disposal method.

have not been prepared. The hypothetical landfill considered by this analysis covers 24 hectares, and contains wastes of which about 11 percent consists of bleached kraft. Based on contaminant concentrations reported for bleached pulp, concentrations in paper products are assumed to be no higher than 36 ppt TCDD and 333 ppt TCDF. A soil cover of 10 to 15 centimeters is assumed to be applied to each facility.

Approximately 128 million tons of municipal waste is generated each year; about 109 million tons of this waste is landfilled. Paper wastes constitute about 36% of the municipal waste stream. Assuming that the same proportion of paper wastes goes to landfills as to other municipal disposal methods, the resulting estimate of the quantity of paper wastes disposed in landfills each year is a little over 39 tons per year. To estimate the quantity of bleached paper wastes that are landfilled, it is assumed that the percentage of paper waste consisting of bleached paper is roughly equivalent to the percentage of paper production consisting of bleached paper, or about 30 percent. These assumptions yield an estimated 12 million tons of bleached paper products disposed in municipal landfills each year.

Surface impoundments are defined as facilities in which pulp and paper mill sludges are stored or disposed on land without a cover layer of soil. For this analysis, it is assumed that sludge contained in such facilities has a higher moisture content than the sludge deposited in landfills, at least during the active phase of a facility's lifetime. A typical plant using this storage/disposal method is assumed to use three impoundments; each impoundment is assumed to be approximately 10.3 hectares in size, and about 4 meters deep.

Twenty facilities in the 104-Mill Study[2] report using surface impoundments for storage and/or disposal of sludge. This method accounts for about 24 percent of the total quantity of sludge production reported in the 104-Mill Study. An average facility impounds about 19,552 dry tons of sludges per year. The maximum reported quantity of sludge disposed in impoundments by a single plant is 23,517 dry tons per year.

Land application serves as both a disposal method for sludge, and as a method for fertilizing and conditioning soil. According to the 104-Mill Study and follow-up conversations with state environmental officials, four mills in three states use pulp and paper sludge for silviculture; two mills in two states apply it agricultural land; and two mills in two states use the sludge to reclaim abandoned mine sites. Conversations with state environmental officials indicate that approximately 300,000 dry metric tons of sludge are being land-applied per year, or about 12 percent of the total quantity of sludge produced by the mills included in the 104-Mill Study. About 10 percent of this quantity is used in mine reclamation, 10 percent in agriculture, and 80 percent in silviculture. The land application sites considered in this analysis cover about the same land area as the typical landfill site modelled in this analysis; however, the depth of the sludge at a land application sites is typically quite different from the depth of a landfill. At a land application site, the sludge is either applied directly to the top of the land, or is incorporated into the top 10-15 centimeters of soil.

---

[2] U.S. EPA (1989). 104-Mill Study data, Office of Water Regulations and Standards, July 26, 1989 version.

Pulp and paper mill sludge may be composted with other materials and then distributed and marketed as a soil amendment for residential gardening and lawn care or for agricultural and commercial purposes. This analysis examines risks from the residential uses of distributed and marketed sludge. According to the 104-Mill Study, seven mills in five states distribute and market at least a portion of their sludge.

Since the actual users of the composted sludge are not known, a hypothetical scenario is used by this analysis to estimate potential human exposure to TCDD and TCDF through this practice. The average homeowner is assumed to apply 0.16 dry metric tons of composted sludge (about 350 pounds) to a 0.016 hectare home garden each year for twenty years. Gardeners may incorporate the compost into garden soil, or may apply it as top-dressing.

Based on data from the 104-Mill Study, the total volume of sludge distributed and marketed by these plants is estimated to be 208,000 dry metric tons per year, or about eight percent of the total quantity of sludge disposed in the U.S. each year. In some cases, the plants in this study reported distribution and marketing as one of two methods of sludge disposal, but did not provide a breakdown of the quantities of sludge disposed by each method. In these cases, this analysis assumes that the entire quantity of sludge produced by the plant is distributed and marketed.

Tables 1.B and 1.C summarize assumptions used in this analysis to characterize the concentrations of TCDD and TCDF in pulp and paper sludge. As can be seen from the tables, the generic analysis uses a single pair of values for TCDD and TCDF concentrations in sludge; these values are used for each method of disposal or use of sludge. Concentrations for a typical facility represent the median of values reported for all mills in the 104-Mill study (regardless of disposal practice). Concentrations used to estimate exposure and risk for the MEI are based on the 90th percentile of reported concentrations. For each sludge management method, the analysis of current practices uses a different approach; estimation of exposure and risks are based on TCDD and TCDF concentrations reported for plants using the particular method under consideration.

Table 1.B. Distribution of TCDD Concentrations in Sludge

	All Plants	Distribution and Marketing	Incineration	Land Application	Landfill	Sludge Pond	Evaporiz. Pond	Compost
N	79	1	15	3	43	14	0	0
M	27	1	4	0	12	3	1	1
Mean	162.9	101	60.1	327	62.1	559	-	-
Std Dev.	464.7	-	59.6	314.5	75.5	1016.7	-	-
Percentiles:								
100%	3800	101	185	681	293	3800	-	-
99%	3800	101	185	681	293	3800	-	-
95%	680	101	185	681	215	3800	-	-
90%	293	101	161	681	173.5	1390	-	-
75%	119	101	106	681	104	680	-	-
50%	51	101	62	220	20	93.4	-	-
25%	12	101	5	80	9.4	31	-	-
10%	3	101	3.6	80	3	3.35	-	-
5%	1.9	101	0	80	1.9	2.25	-	-
1%	0	101	0	80	0	2.25	-	-
0%	0	101	0	80	0	2.25	-	-

N = number of plants reporting sludge concentrations
M = number of plants missing sludge concentration values
100th percentile = maximum value
0th percentile = minimum value

Table 1.C. Distribution of TCDF Concentrations in Sludge

	All Plants	Distribution and Marketing	Incineration	Land Application	Landfill	Sludge Pond	Evaporiz. Pond	Compost
N	79	1	15	3	43	14	0	0
M	27	1	4	0	12	3	1	1
Mean	885.4	1570	455.2	360.3	504.6	2502.4	-	-
Std Dev.	2303	-	745.9	319.7	1131.9	4832.4	-	-
Percentiles:								
100%	17100	1570	2940	610	6740	17100	-	-
99%	17100	1570	2940	610	6740	17100	-	-
95%	2940	1570	2940	610	1760	17100	-	-
90%	1760	1570	1020	610	1300	9200	-	-
75%	799	1570	617	610	574	1400	-	-
50%	158	1570	158	471	90	840	-	-
25%	34	1570	55	0	25	106	-	-
10%	6	1570	25	0	4.55	15.5	-	-
5%	2.4	1570	16	0	2.4	4.25	-	-
1%	0	1570	16	0	0	4.25	-	-
0%	0	1570	16	0	0	4.25	-	-

N = number of plants reporting sludge concentrations
M = number of plants missing sludge concentration values
100th percentile = maximum value
0th percentile = minimum value

Exposure Pathways Considered

For each of the waste management practices described above, humans and wildlife can be exposed to potential health risks if TCDD and TCDF are released into the environment and come in contact with wildlife or humans. Such contact is possible through a variety of possible exposure pathways, including the following, which are considered in this analysis:

- TCDD and TCDF migrate from sludge or landfilled paper to an aquifer underneath the application or disposal site. Humans withdraw drinking water from the aquifer and are exposed.
- Particles of treated soil or sludge become suspended in air. Humans inhale the particles and are exposed to adsorbed TCDD and TCDF.
- TCDD or TCDF from sludge or landfilled paper volatilizes and escapes into the atmosphere. Humans inhale the contaminated air and are exposed.
- TCDD or TCDF from sludge or treated soil are carried by surface runoff to a nearby lake or stream. Humans withdraw drinking water from the contaminated lake or stream and are exposed.
- TCDD or TCDF from sludge or treated soil are carried by surface runoff to a nearby lake or stream. Fish living in the contaminated water take up the contaminants into their tissues. Humans consume the fish and are exposed.
- Soil treated with sludge is used to grow produce for human consumption, or feed for animals. TCDD and TCDF enter the soil, and are taken up into the tissues of crops grown on the treated land. Humans consume the produce or consume the meat and dairy products produced from the feed, and are exposed.
- Human skin comes into contact with soil that has been treated with sludge. Humans are exposed when TCDD and TCDF from the soil are absorbed by the skin.
- Children and adults ingest small quantities of sludge or treated soil and are exposed.
- Wildlife feed in areas treated with pulp and paper sludge. They ingest food items contaminated with TCDD and TCDF, and are exposed.

Table 1.D summarizes the pathways of potential human or wildlife exposure considered for each waste disposal practice. As can be seen from the table, all eight pathways are considered when estimating risks from land application; fewer pathways are considered for other waste management practices.

For each pathway of potential human exposure, this analysis prepares separate exposure and risk estimates for a "most exposed individual" (MEI) and for the total exposed population. The MEI is defined as a hypothetical individual whose circumstances or behavior patterns result in especially high potential exposure through the single exposure pathway under consideration. Such an individual, for example, might consume unusually high quantities of fresh fish, resulting in increased

Table 1.D. Exposure Pathways Evaluated for Each Waste Use or Disposal Practice

Exposure pathway	Sludge landfill	Sludge Paper landfill	Sludge surface impoundment	Sludge land application	Sludge distribution & marketeting
Human exposure					
Ingestion exposure from drinking contaminated groundwater:	•	•	•	•	
Ingestion exposure from drinking surface water contaminated by runoff:	•		•	•	
Ingestion exposure from foods produced with contaminated soil:				•	•
Ingestion exposure from consumption of fish caught in contaminated surface water:	•		•	•	
Ingestion exposure from direct ingestion of contaminated soil:				•	•
Inhalation exposure to volatilized contaminants:	•	•	•	•	•
Inhalation exposure to particulates from contaminated soil:				•	•
Dermal exposure from contact with contaminated soil:				•	•
Wildlife exposure					
Ingestion exposure from ingestion of contaminated food items:				•	

vulnerability through the fish ingestion pathway. For the exposure pathway involving inhalation of volatilized contaminants from a land application site, the "most exposed individual" is defined as someone who lives on the treated land and inhales TCDD and TCDF vapor at local concentrations. A similar MEI definition has been prepared for each waste management practice and exposure pathway.

In addition to estimating exposure and risk for a "most exposed individual", this analysis also considers exposure and risks to broader segments of the U.S. population that might be exposed to lower levels of risk from each pathway. For example, risks from inhalation of volatilized TCDD and TCDF are estimated for all persons living within 50 kilometers of a sludge landfill or surface impoundment. Individuals living closer to the facility will generally be exposed to higher concentrations of contaminant; this analysis maps expected concentrations of TCDD and TCDF in ambient air onto actual populations surrounding each site, and reports estimated average exposure and risk for those populations. Total risks (in expected incremental cancer cases per year) are then estimated for the exposed populations, by multiplying typical individual risk by the size of the exposed population, and dividing by average human life expectancy.

Estimates of human health risks are expressed in terms of lifetime risks of developing cancer as a result of TCDD and TCDF exposure. The human cancer risk of TCDD is assumed to be ($1.5 \times 10^5 / 0.55$) per milligram per kilogram per day; the potency of TCDF is assumed to be one tenth that of TCDD.

Estimates of wildlife risks are computed for nine avian and seven mammalian species assumed to forage on land application sites treated with TCDD- and TCDF-contaminated sludge. Risks are expressed in terms of the percent by which the estimated daily dose exceeds a toxicological "benchmark" dose. For birds, the "benchmark" dose is the dose at which no adverse effects on animals were observed in a laboratory setting. For bird embryos and mammals, the "benchmark" selected is the lowest dose at which adverse effects on animals were observed in laboratory studies.

Key Assumptions Used in Analysis

This analysis uses mathematical models to estimate the extent to which humans and wildlife are exposed to TCDD and TCDF from pulp and paper mill sludge or from landfilled paper wastes. For each waste use or disposal method and for each pathway of potential exposure, it begins by estimating concentrations of TCDD and TCDF in the environmental medium or media of concern. Results are then combined with assumptions about human or wildlife behavior to estimate expected exposure and risk.

As with any modeling effort, the precision of the resulting estimates is a function of the suitability of the mathematical models chosen for the calculations, and of the quality of the assumptions and input parameters used. To the extent that model selection, assumptions or input parameters are based on incomplete or faulty data, the models may over- or under-estimate actual exposure and risk. Assumptions and input parameters used for estimating exposure and risk are described in detail throughout this report. Some of the more fundamental assumptions involved in this analysis are listed below:

- Data from the 104-Mill Study provide an accurate representation of current sludge production, contaminant concentrations, and use and disposal methods.
- Exposure and risk can be estimated based on current sludge management practices, current sludge quality, and current population densities and locations.
- Assumptions regarding management practices (use of liners for landfills, berms for surface impoundments, etc.) are representative of current practices, or of worst case scenarios, where appropriate.
- Assumptions regarding facility siting (distance to surface water, distance to human population, etc.) are realistic.
- Assumptions regarding human behavior (both typical and worst case) are realistic.
- Selected mathematical models provide reasonable predictions of the fate and transport of TCDD and TCDF in environmental media.

Where significant data gaps exist, this analysis attempts to quantify the range of possible error in its exposure and risk estimates. In addition to providing exposure and risk estimates based on the best available models and parameter values, it also provides upper bound and lower bound estimates of human and wildlife exposure through each exposure pathway. "Low risk" estimates are based on a combination of "low risk" parameter values for each key input parameter used in the exposure models. Similarly, "high risk" estimates are derived from combinations of "high risk" assumptions. "Low risk" and "high risk" parameter values are chosen so that true values under actual conditions are unlikely to fall outside the range of values modeled. It then follows that "true" risks are unlikely to fall outside the range bounded by these two estimates[3]. Estimates of exposure and risk based on "best estimates" for each assumption and input parameter are presented throughout this report. Risk and exposure estimates based on "low risk" and "high risk" assumptions are presented in Chapter 4.

---

[3] All cancer risks are estimated based on an upper bound human cancer slope factor. For this reason, actual risks may be lower than the "low risk" estimates derived by this analysis, and may be zero.

Organization of Report

Chapter 2 of this report will describe methods used for estimating the exposure of humans to TCDD and TCDF as a result of the current use or disposal of pulp and paper sludge, and of the landfilling of waste paper. To the extent possible, the assessment will be based on knowledge of site-specific disposal and use practices. Each disposal practice and exposure pathway will be considered separately. Section 2.1 will discuss exposure and risk from disposal of sludge in industrial landfills, Section 2.2 will discuss paper disposal in municipal landfills, Section 2.3 will discuss disposal of sludge in surface impoundments, Section 2.4 will discuss the land application of sludge, and Section 2.5 will consider distribution and marketing of sludge. Within each of these five sections, estimation methods will be described for each pathway of potential exposure, followed by a presentation and brief discussion of results.

Chapter 3 will discuss methods for estimating risks to wildlife associated with the land application of sludge. Section 3.1 discusses toxicity measures to which wildlife exposures are compared, Section 3.2 discusses methods for estimating exposures for wildlife, and Section 3.3 presents results from the analysis.

Chapter 4 will report results from "high risk" and "low risk" estimates of exposure and risk, and discusses key uncertainties in the findings of this analysis. By comparing exposure and risk estimates based on "low risk" and "high risk" assumptions and input parameters, Chapter 4 identifies waste management methods and exposure pathways for which significant uncertainty remains with respect to expected exposure and health risk. Chapter 5 will summarize results from the analysis of current practices and offer some general conclusions and observations. Chapter 6 will present the methodology and results of the analysis of risk based on generic scenarios depicting sludge disposal and use.

The report also contains six appendices. Appendix A discusses methods for estimating concentrations of TCDD and TCDF in soil, and Appendix B discusses methods for estimating contaminant concentrations in surface water and fish. These methods are used for calculations described in several of the preceding chapters. Appendix C compares two methods for estimating exposure through surface water pathways. Appendix D provides additional detail with respect to estimates of exposure for wildlife, Appendix E provides sample calculations to illustrate the methodologies, and Appendix F provides supplemental material for exposure and risk to wildlife.

2.0 Estimates of Exposure and Risks to Humans

This analysis estimates risk for a hypothetical "most exposed individual," and for the entire exposed population in aggregate. "Best estimates" of exposure to the most exposed individual combine reasonable worst-case values for inputs related to individual behavior with best available estimates of physical and chemical model parameters. "High" MEI estimates combine worst-case values for individual behavior and high estimates for the physical and chemical parameters. The aggregate, or total population risk assessment, assesses exposure for more typical individuals, using "low risk", "best estimate", and "high risk" assumptions to reveal the uncertainty implicit in model results. The "low risk" and "high risk" analyses vary from the "best estimate" in both behavior and physical/chemical parameters to reflect uncertainty.

This report focuses on one type of human health risk: cancer. Cancer risks to the "most exposed individual," expressed in terms of increments to an individual's lifetime risk of developing a cancer, are computed as the product of the individual's average daily absorbed dose of TCDD and an upper bound estimate of human cancer potency, or q_1^*, for TCDD. Absorbed dose is computed by multiplying the rate at which TCDD or TCDF contact the body by an absorption fraction (the fraction of chemical contacting the body which enters the body). The TCDD cancer potency estimate used for this analysis (1.5×10^5 per mg/kg/day) is based on animal experiments for which absorption was estimated to be 55 percent. The relationship between absorbed dose and cancer is thus (1.5×10^5 / 0.55).

The cancer potency of TCDF is assumed to be one tenth that of TCDD[1]. Throughout this report, human exposure will be expressed in terms of TCDD equivalency; that is, total absorbed TCDD-equivalent dose will be measured as the total absorbed dose of TCDD plus one tenth the total absorbed dose of TCDF.

Calculation of average risk for the total exposed population is similar to calculations performed for the MEI, except that it requires knowledge of the size of the exposed population. To express population risks in terms of incremental annual cancer cases, this analysis divides total population lifetime cancer risk by the average length of a lifetime, assumed to be 70 years.

---

[1] U.S. EPA (1989). Memo from C. Cinalli to Dioxin-in-Paper Workgroup, July 21.

2.1 Landfills

Landfilling of sludge from the pulp and paper industry is defined as the burial of sludge on land, usually accompanied by the regular application of soil cover. Once a landfill's capacity is exhausted, a permanent cover of soil, clay or other material may be applied to the site. Sludge landfills can be loosely categorized into two groups: industrial facilities that receive only wastes from the pulp and paper industry, and municipal landfills that accept waste as part of a broader waste stream. Fifty-nine of the pulp and paper mills in the 104-Mill Study (U.S. EPA, 1989e) use landfilling to dispose of their sludge. Of these, at least 15 dispose of their sludge in municipal landfills. This analysis assumes that all 59 of the landfills are industrial landfills, and does not perform separate analyses of risk from municipal facilities. Instead, it is assumes that risks from hypothetical industrial facilities can be generalized to municipal landfills.

Table 2.1.A summarizes the characteristics of these hypothetical landfills assumed in the typical risk assessment. These characteristics are intended to be representative of industrial landfills receiving pulp and paper sludge. Table 2.1.B lists landfill characteristics assumed in the MEI analysis. According to U.S. EPA (1985), 30 acres (about 12 hectares) is thought to be a representative area for such landfills, which have an average active lifetime of 14 years. One mill in the 104-Mill study reported landfilling in trenches with depths of up to 20 feet (6 meters); in the absence of data from a broader sample of landfills, this analysis assumes that a typical landfill is 3-6 m in depth. Data from the 104-Mill Study yield an average yearly total of about 20,000 tons (dry weight) of sludge per mill reporting use of landfills. The maximum reported quantity of sludge is 77,000 dry tons per year. "High risk" estimates assume that the landfill covers 60 acres, to a depth of six meters. Tables 2.1.A and 2.1.B also contain assumptions about the chemical and physical properties of TCDD and TCDF. Table 2.1.B lists landfill characteristics assumed in the MEI analysis.

This analysis estimates human exposure to TCDD and TCDF through four exposure pathways associated with sludge landfills:

- Contaminants volatilize from the landfill and are transported by wind to neighboring areas. Humans inhale contaminated air and are exposed.

- Storm runoff caries contaminant-laden particles of soil from the surface of the landfill to nearby surface water bodies. Contaminants are then released from stream or lake sediments into surface water, which is withdrawn for drinking water supplies. Humans ingest the contaminated water and are exposed.

- Storm runoff caries TCDD and TCDF to surface water bodies, as described above. Fish accumulate TCDD and TCDF from the water or sediment. Humans ingest fish and are exposed.

Table 2.1.A. Assumptions and Parameter Values for a Typical Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Area of landfill (cm^2)	1.2×10^9	1.2×10^9	2.4×10^9	30 acres for low and best estimates is thought to be typical. 60 acres is highest reported value.	U.S. EPA (1985). 104-mill study.
Quantity of sludge received (DMT/yr)	19,500	19,500	76,700	Average and highest values reported.	104-Mill study
Landfill dimensions (m x m)	350 x 350	350 x 350	500 x 500	Assumes square site for 30 and 60 acre landfills.	
Facility lifetime (yrs)	14	14	14		U.S. EPA (1985)
Depth of landfill (m)	6	6	6	One landfill reported depth of 20 feet.	104-Mill study.
Site locations	Location of town containing each landfill.				104-Mill study
Fraction organic carbon in cover	1%	1%	NA		U.S. EPA (1988).
Fraction organic carbon in sludge	25%	25%	14%	Median nitrogen content in combined sludges is 0.85%. Typical organic carbon-to-nitrogen ratios range from 17:1 to 45:1	NCASI (1984).

Table 2.1.A. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Fraction organic carbon in landfill soil	20%, 10%	20%, 10%	14%	Low-risk and best estimates distribute OC between two layers of sludge and soil. High estimates assumes pure sludge as fill contents.	
Soil porosity	0.25	0.25	0.25	Typical values.	
Soil disconnectiveness index	3.7	3.7	NA	Typical values	
Soil intrinsic permeability (cm^2)	1×10^{-8}	1×10^{-8}	NA	Within range of permeabilities reported for "silty sand" and "clean sand".	Freeze and Cherry (1979).
True density of sludge/soil	2.65	2.65	2.65	Density of quartz.	
Bulk density of soil (kg/m^3)	1,400	1,400	1,400	Typical value for sand.	Yeh (1981).
TCDD concentration in sludge (ng/kg)	62	62	293	Average and highest reported values from landfills.	104-Mill study.
TCDF concentration in sludge (ng/kg)	520	520	6,740	Average and highest reported values from landfills.	104-Mill study.

Table 2.1.A. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	3.5×10^4	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

Notes: NA = Not Applicable.

Table 2.1.A. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).

Table 2.1.B. Assumptions and Parameter Values for the Most Exposed Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Area of landfill (cm^2)	2.4×10^9	2.4×10^9	2.4×10^9	Largest reported area (60 acres).	104-mill study.
Quantity of sludge received (DMT/yr)	76,700	76,700	76,700	Average and highest values reported.	104-Mill study
Landfill dimensions (m x m)	500 x 500	500 x 500	500 x 500	Assumes square site for 30 and 60 acre landfills.	
Facility lifetime (yrs)	14	14	14		U.S. EPA (1985)
Depth of landfill (m)	6	6	6	One landfill reported depth of 20 feet.	104-Mill study.
Site locations	Location of town containing each landfill.				104-Mill study
Depth of cover (cm)	10	10	0	High risk estimate based on landfill without cover.	U.S. EPA (1988).
Fraction organic carbon in cover	1%	1%	NA		U.S. EPA (1988).
Fraction organic carbon in sludge	25%	25%	14%	Median nitrogen content in combined sludges is 0.85%. Typical organic carbon-to-nitrogen ratios range from 17:1 to 45:1	NCASI (1984).

Table 2.1.B. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Fraction organic carbon in landfill soil	20%, 10%	20%, 10%	14%	Low-risk and best estimates distribute OC between two layers of sludge and soil. High estimates assumes pure sludge as fill contents.	
Soil porosity	0.25	0.25	0.25	Typical values.	
Soil disconnectiveness index	3.7	3.7	NA	Typical values	
Soil intrinsic permeability (cm^2)	1×10^{-8}	1×10^{-8}	NA	Within range of permeabilities reported for "silty sand" and "clean sand".	Freeze and Cherry (1979).
True density of sludge/soil	2.65	2.65	2.65	Density of quartz.	
Bulk density of soil (kg/m^3)	1,400	1,400	1,400	Typical value for sand.	Yeh (1981).
TCDD concentration in sludge (ng/kg)	NA	293	293	Highest reported concentration for landfills.	104-Mill study.
TCDF concentration in sludge (ng/kg)	NA	6,740	6,740	Highest reported concentration for landfills.	104-Mill study.

Table 2.1.B. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).

Table 2.1.B. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	3.5×10^4	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

Notes: NA = Not Applicable.

- Rain water or sludge moisture carry dissolved contaminants from the bottom of the landfill to an aquifer underneath a landfill. Dissolved contaminants are then transported by the aquifer to nearby drinking water wells. Humans ingest contaminated water withdrawn from the wells and are exposed.

Each of these pathways of potential human exposure is discussed below.

2.1.1 Estimates of Exposure and Risks from Inhalation of Vapors

Estimating human exposure and risk through the volatilization pathway involves at least three steps. First, one must estimate the extent to which TCDD and TCDF are emitted from each landfill site. Second, one must estimate the extent to which air concentrations of these contaminants will be reduced through wind transport and atmospheric decay processes. Finally, one must map resulting air concentrations onto nearby populations in order to estimate the extent of human exposure and total human health risks. Inputs for typical and MEI exposure to vapor from landfills are found in Tables 2.1.C and 2.1.D, respectively.

Methods for Estimating Emissions

This analysis explores two approaches for the first of these steps. The simpler approach uses a set of equations from U.S. EPA (1986), and Hwang and Falco (1986) as described in U.S. EPA (1988b), to predict emissions from a landfill site. It assumes that emissions from the landfill (in g/m^2/second) are described by:

$$N_a = \frac{2D_i E^{4/3} K_{as} C_{so}}{[\pi \alpha T]^{1/2}} \qquad (2.1.1)$$

where:

$$\alpha = \frac{D_i E^{4/3}}{E + p_s(1-E)/K_{as}} \qquad (2.1.2)$$

$$K_{as} = 41\ H_c/K_D \qquad (2.1.3)$$

and:

D_i = the molecular diffusivity of contaminant vapor in air (cm/second),

C_{so} = the initial contaminant concentration in the soil (g/g),

E = effective porosity of soil (unitless),

H_c = Henry's law constant (atm m^3 / mol),

Table 2.1.C. Assumptions and Parameter Values for a Typical Individual - Landfills: Volatilization Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate emissions	SESOIL	SESOIL	U.S. EPA (1988)	Low and best estimates based on "typical" landfill modeled with SESOIL. High estimate based on "worst case" landfill modeled with EPA (1988) methodology.	Bonazountas and Wagner (1984); U.S. EPA (1988); Hwang and Falco (1986) and U.S. EPA (1986) in U.S. EPA (1988).
Depth of cover (cm)	10	10	0	High risk estimate based on landfill without cover	U.S. EPA (1988).
Model used to estimate wind transport and human exposure	ISCLT (area source)	ISCLT (area source)	ISCLT (area source)	Location - specific modeling for each site.	Bowers et al. (1980); GEMS; U.S. EPA (1984.
Metereological data for ISCLT	STAR data accessed through GEMS (site specific).				GEMS; U.S. EPA (1984).
Emission period (yrs.)	70	70	70	Corresponds to length of exposure for cancer risk calculations.	
Landfill status at beginning of emission period	Full	Full	Full	Will tend to overestimate emissions.	
Population densities and locations	Census data accessed through GEMS (site specific).				GEMS.

Table 2.1.D. Assumptions and Parameter Values for the Most Exposed Individual - Landfills: Volatilization Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate emissions	SESOIL	SESOIL	U.S. EPA (1988)	Low and best estimates based on "typical" landfill modeled with SESOIL. High estimate based on "worst case" landfill modeled with EPA (1988) methodology.	Bonazountas and Wagner (1984); U.S. EPA (1988); Hwang and Falco (1986) and U.S. EPA (1986) in U.S. EPA (1988).
Depth of cover (cm)	10	10	0	High risk estimate based on landfill without cover	U.S. EPA (1988).
Model used to estimate wind transport and human exposure	ISCLT (area source)	ISCLT (area source)	ISCLT (area source)	Location - specific modeling for each site.	Bowers et al. (1980); GEMS; U.S. EPA (1984.
Metereological data for ISCLT	STAR data accessed through GEMS (site specific).				GEMS; U.S. EPA (1984).
Emission period (yrs.)	70	70	70	Corresponds to length of exposure for cancer risk calculations.	
Landfill status at beginning of emission period	Full	Full	Full	Will tend to overestimate emissions.	
Population densities and locations	Census data accessed through GEMS (site specific).				GEMS.

p_s = true density of soil (g/cm3),

K_D = the soil/water partition coefficient (cm^3/g),

K_{as} = the air/soil partition coefficient (mg/cm^3 in air per mg/g in soil),

N_a = rate of emissions from the soil surface (g/m^2/second),

T = duration of exposure (seconds).

U.S EPA (1988b) used a numerical solution of a partial differential equation to determine the reduction in volatile emissions that would be expected following the addition of a soil layer to the top of a landfill. For a 10 to 25 centimeter soil cover, EPA estimated that emission rates were reduced by 75 to 80 percent, given a contaminated layer thickness of 8 feet. Criteria for design and operating characteristics for industrial landfills are not currently available. Consequently, the extent to which daily and final cover are used at landfills is not known. For a "high risk" scenario of potential human exposure, this analysis therefore assumes that the landfilled sludge is left uncovered for the exposure period of concern.

The second approach uses results from the SESOIL model (Bonazountas et al. 1984, U.S. EPA, 1987b). SESOIL uses Farmer's equation (Farmer et al., 1980) to estimate the movement of volatilized contaminant between layers of the soil column, and to estimate releases of the contaminant from the topmost layer to the ambient air:

$$Na = \frac{D_a [(n-\Theta)^{10/3} H c}{n^2 R (T+273) L} \qquad (2.1.4)$$

where:

Na = pollutant flux across soil surface (ug/cm^2/sec),

D_a = diffusion coefficient of compound in air (cm^2/sec),

H = Henry's law constant (m^3 atm/mol),

R = gas constant (8.2×10^{-5} m^3 atm/mol K),

T = temperature (Centigrade),

c = concentration of compound in soil moisture (ug/ml),

n = soil porosity (unitless),

Θ = soil moisture (unitless), and

L = depth of soil layer.

As can be seen from Equation 2.1.4, contaminant emissions, as estimated by SESOIL, are sensitive to assumptions concerning the depth of soil cover, soil porosity and moisture content. An advantage of using the SESOIL model is that it automatically maintains a mass balance between initial contaminant loadings and the amounts of contaminant released or retained by each soil sub-layer. Contaminant releases to groundwater or ambient air are thus estimated simultaneously.

Methods for Estimating Wind Transport of Volatile Emissions

Once volatilized TCDD or TCDF is emitted from a landfill, it can be transported downwind to nearby residents, resulting in potential human exposure and health risks. This analysis uses a Gaussian plume dispersion model to estimate the extent to which air concentrations of TCDD and TCDF will be reduced in the process of wind transport. Calculations are performed by the area source version of ISCLT (Industrial Source Complex, Long Term) model (Bowers et. al, 1980) incorporated into the Graphical Exposure Modeling System (GEMS) maintained by the U.S. EPA Office of Toxic Substances (U.S. 1989b,d). The model estimates ambient air concentrations at selected locations in a polar grid centered on the emission site and extending 50 km in all directions. In addition to its simulation of contaminant dispersion in the plume downwind of a landfill site, the model also considers losses of contaminant due to photolysis and other first-order decay processes. It then maps those air concentrations onto actual human populations for the regions involved. Population data are drawn from the 1980 Census, mapped to the level of Census block group and enumeration district. The MEI for this analysis is defined as the human population located in the grid cell with the highest estimated concentration of TCDD and TCDF.

ISCLT performs site-specific exposure calculations for each landfill site under consideration. Because specific information required to estimate emissions of TCDD and TCDF to air at each site was not available, all landfill sites in the inventory are assumed to be of identical size, to contain sludge with the same concentrations of TCDD and TCDF, to use the same management practices, and therefore to emit contaminants at identical rates. As summarized in Tables 2.1.A through 2.1.D, these assumptions vary between "best estimate" and "high risk" estimates, but are applied consistently across all facilities. In short, wind transport and exposure calculations are site-specific, but emission estimates are not.

Methods for Estimating Human Exposure and Risk

Based on estimated concentrations of TCDD and TCDF in ambient air, individual exposure and cancer risk are calculated by:

$$I_{RD} = E_D\, q^*$$

where:

$$E_D = \frac{C_D\, I_H\, F_A\, LF}{BW\, LE}$$

and:

BW = average body weight (assumed to be 70 kg)

C_D = estimated air concentration at distance D (mg/m^3)

E_D = average lifetime individual exposure for person residing at distance D (mg/kg/day)

I_H = volume of air inhaled daily (assumed to be 23 m^3/day, after U.S. EPA, 1985)

I_{RD} = lifetime individual cancer risk for person residing at distance D (lifetime^{-1})

LE = life expectancy (assumed to be 70 years)

LF = number of years of exposure per lifetime (assumed to be 70 years/lifetime)

q^* = cancer slope factor for TCDD or TCDF (mg/kg/day)$^{-1}$

ISCLT provides estimates of population-weighted average concentrations of the TCDD or TCDF in ambient air surrounding all landfill facilities. Aggregate cancer risks are calculated with following expression:

$$E_{AVE} = \frac{C_{AVE}\, I_H\, F_A\, L_F}{BW\, LE}$$

$$R_T = E_{AVE}\, q^*\, POP / LE$$

where:

C_{AVE} = average air concentration of contaminant, computed by weighting each level of contaminant concentration by the number of persons exposed to that level (mg/m^3)

E_{AVE} = population-weighted average exposure for all persons living within 50 km of a pulp and paper sludge landfill (mg/kg/day)

POP = total exposed population

R_T = aggregate cancer risk for exposed population (incremental cancer cases/year)

and all other variables are as described above.

Data Sources and Model Inputs for Estimating Volatile Emissions

Soil-water partition coefficients (K_D) for TCDD and TCDF are derived by assuming that the organic carbon content of the sludge is approximately 14 percent, resulting in partition coefficient values of 1.4×10^6 and 4,900 respectively for TCDD and TCDF. These values combine in Equation 2.1.3 to yield an estimated K_{as} value of 5×10^{-10} for TCDD and 7×10^{-7} for TCDF. Substituting this value into Equation 2.1.2 and 2.1.1 yields estimated emissions of 2×10^{-16} grams per m^2 per second for TCDD and 2×10^{-13} grams per m^2 per second for TCDF. These results are used to derive "high risk" estimates of human exposure and risk through this pathway.

Eduljee (1987), uses a different theoretical model from the one just discussed for estimating TCDD emissions from soils. The sample calculations for the method (which is based on Jury et al., 1984) assume a soil temperature of 25 degrees Centigrade, porosities ranging from 0.1 to 0.5, bulk density of 1350 kg/m^3, evaporation from 0 to 0.5 mm/day, and time periods ranging from 1 to 3,000 days. The calculations assume a K_{oc} of 1.1×10^6 for TCDD, and an organic carbon content of 0.0125. Resulting estimates, for an initial loading of 1 kg TCDD per m^3 of soil, range from 7×10^{-8} to 7×10^{-7} kg/m^2/day, or 8×10^{-10} to 8×10^{-9} g/m^2/sec. Scaling these estimates for an initial concentration of 293 ng/kg in sludge/soil (the highest value reported for landfilled sludge in the 104-Mill Study) suggests emission estimates ranging from 3×10^{-16} to 3×10^{-15} g/m2/sec. These results are consistent with the estimate of 2×10^{-16} derived above (based on a higher assumed value for the fraction of organic carbon, and a higher value for K_{oc}).

In simulations using assumptions and input parameters from Tables 2.1.A and 2.1.C, SESOIL predicts that approximately 4×10^{-24} grams of TCDD and 8×10^{-18} grams of TCDF will be emitted per second per square meter of landfill area. These results are significantly lower than emissions estimated with Equations 2.1.1 through 2.1.3. Sensitivity testing of the SESOIL model has shown that model results are sensitive to assumptions regarding the layer depths chosen for the simulation, and to the assumed moisture content and effective porosity of the sludge-soil mixture in the landfill.

Data Sources and Model Inputs for Estimating Wind Transport

Most inputs for the ISCLT model were obtained from data bases accessed automatically through GEMS. To run the model, GEMS must be supplied with latitude and longitude coordinates for each town containing a sludge landfill. It is assumed that the each landfill has a width of 350 meters.

Current literature reports a range of rates of atmospheric decay for TCDD. Podoll et al. (1988), for example, found that photolysis dominates the decay process, with hydrolysis playing a lesser role. They derived a lower bound estimated half-life of 58 minutes for TCDD vapor in sunlight. The authors point out, however, that the extent to which adsorption to particulates might decrease these estimated rates is unknown. Mill et al. (1987) reported that TCDD adsorbed to fly ash evidenced half life values of several hundred hours. Atkinson (1987) calculated an atmospheric half-life of 3 days for TCDD, based on the OH radical reaction. "Best estimate" calculations for this report assume a atmospheric half life of 3 days for TCDD, high risk estimates assume that atmospheric losses are insignificant. For lack of corresponding data for TCDF, the same rates of atmospheric decay are used for TCDF as for TCDD.

Results from ISCLT suggest that the times of wind transport to exposed populations within 50 km of known landfill sites range from about ten minutes to four hours, with a population-weighted average of about 30 minutes. If the atmospheric half-life of TCDD is indeed three days, then losses over this time interval will be relatively small.

2.1.2 Groundwater Pathway

Humans can be exposed to potential health risks from landfills if leachate beneath a sludge landfill enters the groundwater and is transported to nearby drinking water wells. Because of its hydrophobicity and low solubility, however, the mobility of TCDD in soil is thought to be quite low. Helling et al. (1971), for example, describes TCDD as "immobile" in soil. Other researchers have detected downward movement of TCDD through soil, but at low rates. Freeman and Schroy (1985), for example, found that TCDD from a biodegradation test plot at Eglin Air Force Base had dispersed 10 cm in 12 years. They explained the detected mobility as a consequence of temperature gradients in the soil; these results cannot necessarily be generalized to the zone beneath sludge landfills, where temperature gradients and other conditions are likely to differ from those observed at Eglin.

Mobility of TCDF is not as well studied. TCDF has a higher solubility in water, and a lower soil/water partition coefficient, however, and may therefore pose a greater threat for human exposure and risk from landfills. For lack of sufficient empirical data, this analysis must rely on mathematical models to estimate the extent of possible human exposure and risk from both TCDD and TCDF in sludge landfills.

Potential risks are determined by the concentration of TCDD and TCDF in the landfill, site characteristics and management practices, local meteorological conditions, depth to groundwater beneath the landfill site, the vadose medium or media between the landfill and the saturated zone, characteristics of the aquifer receiving the loading of contaminated water from the site, and downgradient distances from the site to wells providing drinking water. Most of these characteristics vary significantly from site to site; constructing a "typical" hypothetical scenario is therefore difficult, if not impossible. If risks from a "worst case" hypothetical scenario could be shown to be insignificant, however, then one might reason that risks from actual facilities are likely to be insignificant as well.

Based on a "worst case" hypothetical landfill scenario, U.S. EPA (1988b) examined potential risks of human exposure to TCDD from groundwater contamination beneath landfills, and concluded that

> "... because of very high retardation of 2,3,7,8-TCDD by the ground water media, the concentration in ground water will be small, and ground water is not a significant pathway for 2,3,7,8-TCDD migrating from landfill sites. However, ... if cosolvents are present in the landfill or if channeling occurs, the mobility of 2,3,7,8-TCDD may be significantly increased."

These conclusions rely on analysis of a hypothetical worst case scenario in which leachate containing TCDD at its solubility limit enters a shallow aquifer with low organic carbon content. A semi-analytical three dimensional area source model was used to predict well water concentrations at distances varying from 15 to 152 meters from the landfill site. Comparison of results for similar scenarios using the AT123D model (Yeh, 1981), however, suggest that concentrations at the test wells would continue to increase beyond the 100 year period simulated by U.S. EPA (1988b), and could eventually reach levels of TCDD contamination associated with significant cancer risks for a most exposed individual (MEI). Based on the parameter values listed in Table 2.1.D, estimated expected groundwater concentrations are estimated for both TCDD and TCDF. At peak well concentrations, these levels would be associated with cancer risks of 3×10^{-5} for TCDD, and 6×10^{-4} for TCDF. The higher solubility of TCDF, together with its lower K_D value, helps explain its higher estimated risks.

As mentioned by U.S. EPA (1989b), exposure and risks could be higher if the presence of co-solvents increases the mobility of TCDD and TCDF. Mobility might also be enhanced if these contaminants bind to more water soluble organic molecules. Enfield and Bengtsson (1988b), used laboratory experiments to examine the relative mobility of organic compounds with and without the presence of dissolved macromolecules. They concluded:

> "When a municipal landfill which produces large amounts of dissolved organic carbon is co-disposed with toxic hydrophobic chemicals, the large amounts of DOC produced by the natural degradation processes will make conditions favorable to the transport of hydrophobic materials normally considered immobile."

Since upper bound risk estimates cannot rule out the possibility of significant risks from TCDD and TCDF through groundwater contamination, this analysis attempts to quantify potential exposure and risk to both TCDD and TCDF from landfills receiving sludge from the pulp and paper industry. It is hindered by the limited availability of site-specific data for pulp and paper sludge landfills, and necessarily relies on numerous simplifying assumptions. Nevertheless, it is thought to provide at least a rough estimate of the risks that may be associated with landfills.

Methods for Estimating Contaminant Loadings to Groundwater

Estimating human exposure and risk from groundwater contamination involves two steps. The first step is to determine the extent to which sludge contaminants are transported through the soil (or sludge) medium above the aquifer. Once loadings to the aquifer have been estimated, the second step is to estimate how much concentrations of TCDD and TCDF will be reduced during transport through the aquifer. The third step is to determine the size of exposed populations, based on estimates of the number of wells likely to be affected.

Leachate concentrations and quantities beneath a landfill are estimated with two separate methods. In the first, leachate concentrations of TCDD and TCDF beneath an industrial landfill (with no significant co-solvent effects) are assumed unlikely to exceed levels predicted on the basis of equilibrium partitioning of sludge contaminants between dissolved and adsorbed phases. The second approach uses the SESOIL model (Bonazountas et al., 1984, U.S. EPA, 1987b) to simulate the transport of TCDD and TCDF through the contents of a landfill and the unsaturated zone beneath it. Each of these two approaches will now be discussed.

Using Equilibrium Partitioning to Predict Loadings to Ground Water

Upper bound estimates[1] of plausible dissolved TCDD and TCDF concentrations in leachate as it enters the saturated zone can be derived from reported sludge concentrations from pulp and paper mills using landfills. Given the unusually high solid/liquid partition coefficient for TCDD (and to a lesser extent for TCDF) leachate concentrations will be greatly influenced by the tendency of these two chemicals to adsorb to soil particles. Maximum leachate concentrations can be estimated from sludge concentrations based on the following definitions:

$$C_{DW} = \frac{M_{CS} + M_{CW}}{M_S}$$

---

[1] These "upper bound" estimates ignore possible effects of cosolvents or dissolved organic carbon on rates of TCDD and TCDF migration from the sludge.

$$C_W = \frac{M_{CW}}{M_W}$$

$$K_D = \frac{M_{CS}\, M_W}{M_S\, M_{CW}}$$

where:

M_{CS} = mass of adsorbed contaminant in landfill (ug)
M_{CW} = mass of dissolved contaminant in landfill (ug)
M_S = mass of solid contents in landfill (g)
M_W = mass of liquid in landfill (g)
C_{DW} = concentration (dry weight) of contaminant in sludge (ug/g)
C_W = concentration of contaminant in liquid (ug/g)

If:

$$M_W = M_S\, p / N$$

where:

p = bulk density of soil (g/cm^3)
N = porosity of soil (unitless)

then it follows that:

$$C_W = \frac{C_{DW}}{K_D + (N/p)} \qquad (2.1.4)$$

For values of K_D appropriate for TCDD and TCDF, the second term in the denominator of Equation 2.1.4 can be ignored.

Equation 3-4 predicts maximum concentrations of TCDD and TCDF in leachate leaving the landfill, based on dry-weight concentrations in sludge placed in the facility. These estimates are likely to over-predict actual concentrations, for at least three reasons. First, leachate concentrations will be lower than predicted values to the extent that equilibrium partitioning is not achieved in the time required for water to percolate through the sludge zone. Second, these methods do not consider contaminant losses through volatilization or other removal processes. Third, the store of TCDD and

TCDF in an inactive landfill will decrease over time, possibly resulting in reduced leachate concentrations. On the other hand, these methods do not consider the possibility that co-solvents or dissolved macromolecules might increase the mobility of these contaminants from landfill sites.

Using SESOIL to Predict Loadings to Groundwater

The SESOIL model allows a more comprehensive approach to contaminant transport through soil layers. The model considers monthly climate data, and maintains a mass balance for contaminant transport through multiple soil layers. "Best estimates" of potential human exposure and risks through the groundwater pathway, are derived by using the SESOIL model to simulate TCDD and TCDF transport to the aquifer once steady state conditions have been reached in the unsaturated zone. The simulation assumes that the upper three meters of a pulp and paper sludge landfill contain pure sludge, and the lower three meters contain soil into which TCDD, TCDF, and organic carbon from the sludge have migrated. At steady state, the top three meters are assumed to contain 20 percent organic carbon; the lower three meters contain 10 percent. Using parameter values listed in Tables 2.1.A, 2.1.B, 2.1.C, and 2.1.D, SESOIL simultaneously estimates movement of TCDD and TCDF from the landfill to both ground water and ambient air. Loadings to ground water are proportional to assumed recharge beneath the landfill. A value of 43 centimeters recharge per year has been selected based on GEMS data for a county in Wisconsin.

Using AT123D to Predict Contaminant Transport through the Aquifer

From estimated loadings of TCDD and TCDF to groundwater, the AT123D model (Yeh, 1980), can be used to predict contaminant concentrations at wells down-gradient of the site. Exposure estimates in this analysis are based on "steady state" results from AT123D.

Methods for Estimating Individual Exposure and Risk

Based on assumed rates of individual water ingestion per day, duration of exposure, and rates of absorption of TCDD and TCDF from drinking water, individual exposure and cancer risk are calculated by:

$$I_{RD} = E_D q^*$$

where:

$$E_D = W F_A C_D/BW$$

and:

W = amount of water consumed daily (liters),

F_A = fraction of contaminant absorbed from ingested water (unitless),

E_D = average lifetime individual exposure (mg/kg/day),

C_D = estimated water concentration at distance D (mg/l),

BW = average body weight (assumed to be 70 kg),

I_{RD} = lifetime individual cancer risk (lifetime^{-1}), and

q^* = cancer slope factor for TCDD or TCDF $(\text{mg/kg/day})^{-1}$.

Exposure and risk are estimated separately for persons taking drinking water at each of the three model distances from a surface landfill site. Maximum exposure and risk is assumed to occur at the nearest well location.

Methods for Estimating the Size of Exposed Populations

Estimation of aggregate population risk and exposure requires data describing the location of all nearby drinking water wells relative to each landfill. Ideally, these data could be compared with site specific mapping of groundwater flow to identify those wells vulnerable to contamination from each site. Next, information about the number of persons using each well for drinking water would be needed to estimate the sizes of potentially exposed populations. Such site-specific data could not be obtained for this analysis, which must therefore rely on indirect methods for estimating the sizes of exposed populations. This analysis derives estimates of exposed populations from data available at the county level.

At least two such sources are available. The National Well-Water Association maintains a database describing the number of private wells in each county in the United States. The FRDSPWS data base maintained in GEMS (U.S. EPA 1989d) contains data describing public water supply systems that rely on groundwater as their water source. These data are combined with estimates of the total area, population, and number of households in each county to derive estimates of exposed populations. The calculations are as follows:

$$PGW_{CR} = DGW_C \ A_R \ FG \qquad (2.1.5)$$

where:

$$PGW_C = W_C \ (Pop_C/HH_C) + PS_C \qquad (2.1.6)$$

$$DGW_C = \frac{PGW_C}{A_C} \qquad (2.1.7)$$

and:

PGW_C = estimated number of persons drinking water from wells in county C

W_C = number of private wells in county C

Pop_C = population of county C

HH_C = number of households in county C

PS_C = number of persons using public water systems based on groundwater in county C

DGW_C = density of persons using groundwater in county C (persons/m^2)

A_C = total area of county C

A_R = area of ring R surrounding a landfill (m^2)

PGW_{CR} = estimated number of persons using well water within ring R for a landfill in county C

FG = fraction of each ring down-gradient of the landfill (assumed to be 1/4)

The first step is to estimate the number of persons using groundwater in each county (Equation 2.1.6). The number of persons relying on private wells can be calculated by assuming that each private well reported in the National Well Water Association data represents a single household. Multiplying this number of households using private wells by the ratio of persons per household for the county of concern, yields an estimate of the number of persons using private wells. This estimate is combined with the county's total population using groundwater-based public systems, as reported in FRDSPWS. The next step is to estimate the average density of persons using wells in a particular county, by dividing the total just estimated by the total area of the county (Equation 2.1.7). Finally, the estimated density calculated for each relevant county is multiplied by the area of each hypothetical "ring" of area around the facility (Equation 2.1.5), and adjusted for the fraction of that area expected to be down-gradient of the site (arbitrarily assumed to be 0.25).

Of course, wells are not distributed evenly in a typical county, so the average densities used for this analysis may not actually apply for areas surrounding pulp and paper sludge landfills. Further, the density of persons using public systems will be concentrated at a few select locations, unlikely to fall within the plume down-gradient of a landfill. For public systems, the relatively small probability that a large public system will be affected can be considered equivalent in resulting risk to the assumption that a small fraction of the population served by each system is exposed.

Table 2.1.E shows data from the DRASTIC data base (Aller et. al., 1985) for each of the counties containing mills that dispose of their sludge in landfills. The DRASTIC data base, as accessed through GEMS, describes the distribution of various geo-hydrological characteristics for every county in the U.S. For a specified county, DRASTIC might report, for example, that the most common aquifer medium is sand and gravel (80 percent) followed with lesser frequency by sand and gravel mixed with silt and clay (20 percent). Table 2.1.E presents the most common reported value for each of the seven characteristics reported for each county of concern. As can be seen from the table, the most frequently reported profiles differ from county to county, although certain characteristics seem to be more common than others. Table 2.1.E suggests that depths to groundwater of less than 6 meters are quite common in counties containing sludge landfills. In addition, conversations with permitting authorities for one mill's landfill indicated that groundwater at its highest yearly level rises to within about 0.5 meters of the bottom of the landfill.

Table 2.1.F lists key assumptions and input parameters used to estimate groundwater contamination for pulp and paper sludge landfill. Peak loading of TCDD and TCDF to groundwater is determined by yearly recharge from the landfill site to the aquifer and the dissolved contaminant concentrations in that recharge. Table 2.1.F shows the values for yearly recharge assumed for this analysis. These values and the monthly climate data required for SESOIL runs were obtained from GEMS for a sludge landfill site in Wisconsin. Tables 2.1.G and 2.1.H summarize other inputs for the typical and MEI groundwater exposure assessments, respectively.

As explained above, this analysis uses two methods to predict contaminant concentrations for water entering the saturated zone beneath a landfill. For the first, concentrations of dissolved TCDD and TCDF entering the aquifer beneath a site depends on the concentration of each contaminant in the sludge, and the estimated fraction of organic carbon in the sludge/soil within the landfill.

According to NCASI (1984), the median concentration of organic nitrogen in combined sludge is 0.85 percent, and typical ratios of organic carbon to nitrogen range from 16:1 to 46:1. These values suggest that organic carbon content in sludge is likely to range from about 14 to 40 percent, with a midpoint of about 25 percent. For "worst case" estimates of water concentrations, this analysis assumes that the entire volume of the landfill is filled with pure sludge, and that the concentration of organic carbon throughout the sludge is 14 percent. If there exists a linear relationship between the soil concentration of organic carbon and the partition coefficient for each contaminant, then the rate at which the contaminants migrate through the soil will be inversely proportional to the assumed

Table 2.1.E. Characteristics of Counties with Sludge Landfills

Observation	Depth (meters)	Recharge (cm/yr)	Aquifer medium	Vadose medium	Hydraulic conductivity (meters/sec)
1	9.1-15.2	17.8 - 25.4	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
2	9.1-15.2	0 - 5.1	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
3	9.1-15.2	17.8 - 25.4	Limestone mass1	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
4	9.1-15.2	17.8 - 25.4	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
5	9.1-15.2	17.8 - 25.4	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
6	9.1-15.2	17.8 - 25.4	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
7	4.6-9.1	0 - 5.1	Sand gravel	Silt / clay	$3 \times 10^{-4} - 5 \times 10^{-4}$
8	3.1-4.6	0 - 5.1	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
9	30.5+ m	0 - 5.1	Basalt	Basalt	$5 \times 10^{-7} - 5 \times 10^{-5}$
10	1.5-3.1	5.1 - 10.2	Limestone karst	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
11	0 - 1.5m	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
12	0 - 1.5m	17.8 - 25.4	Sand gravel	Sand gravel	$5 \times 10^{-7} - 5 \times 10^{-5}$
13	0 - 1.5m	17.8 - 25.4	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
14	0 - 1.5m	25.4+	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
15	1.5-3.1	5.1 - 10.2	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
16	9.1-15.2	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
17	0 - 1.5m	17.8 - 25.4	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
18	23.9-30.5	17.8 - 25.4	Sand gravel	Sand gravel	$5 \times 10^{-7} - 5 \times 10^{-5}$
19	23.9-30.5	25.4+	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
20	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
21	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
22	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
23	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
24	3.1-4.6	17.8 - 25.4	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
25	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
26	3.1-4.6	17.8 - 25.4	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
27	1.5-3.1	17.8 - 25.4	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
28	9.1-15.2	0 - 5.1	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
29	9.1-15.2	5.1 - 10.2	Sand gravel	Silt / clay	$1 \times 10^{-4} - 3 \times 10^{-4}$
30	9.1-15.2	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
31	3.1-4.6	25.4+	Meta ign/wth	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
32	0 - 1.5m	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
33	1.5-3.1	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
34	4.6-9.1	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
35	23.9-30.5	10 - 17.8	Meta ign/wth	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
36	4.6-9.1	0 - 5.1	Ss,ls,sh thnbed	ls,ss,sh bded	$5 \times 10^{-7} - 5 \times 10^{-5}$
37	15.2-23.9	10 - 17.8	Basalt	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
38	15.2-23.9	10 - 17.8	Basalt	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
39	4.6-9.1	17.8 - 25.4	Ss,ls,sh thnbed	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
40	4.6-9.1	17.8 - 25.4	Ss,ls,sh thnbed	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
41	3.1-4.6	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
42	4.6-9.1	10 - 17.8	Ss,ls,sh thnbed	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
43	30.5+ m	0 - 5.1	Ss,ls,sh thnbed	Ls,ss,sh bded	$5 \times 10^{-7} - 5 \times 10^{-5}$
44	30.5+ m	5.1 - 10.2	Ss,ls,sh thnbed	Ls,ss,sh bded	$5 \times 10^{-7} - 5 \times 10^{-5}$
45	23.9-30.5	5.1 - 10.2	Ss,ls,sh thnbed	Ls,ss,sh bded	$5 \times 10^{-7} - 5 \times 10^{-5}$
46	3.1-4.6	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
47	30.5+ m	0 - 5.1	Ss,ls,sh thnbed	Ls,ss,sh bded	$5 \times 10^{-7} - 5 \times 10^{-5}$
48	15.2-23.9	5.1 - 10.2	Sand gravel	Sand gravel	$5 \times 10^{-7} - 5 \times 10^{-5}$
49	30.5+ m	0 - 5.1	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
50	15.2-23.9	5.1 - 10.2	Sand gravel	Snd&gvl snd&clay	$3 \times 10^{-4} - 5 \times 10^{-4}$
51	9.1-15.2	0 - 5.1	Meta ign/wth	meta igneous	$5 \times 10^{-7} - 5 \times 10^{-5}$
52	15.2-23.9	5.1 - 10.2	Sand gravel	Sand gravel	9×10^{-4} +
53	4.6-9.1	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
54	4.6-9.1	5.1 - 10.2	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
55	3.1-4.6	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
56	3.1-4.6	10 - 17.8	Sand gravel	Silt / clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
57	3.1-4.6	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$
58	4.6-9.1	10 - 17.8	Sand gravel	Sand gravel	$5 \times 10^{-7} - 5 \times 10^{-5}$
59	3.1-4.6	10 - 17.8	Sand gravel	Snd&gvl snd&clay	$5 \times 10^{-7} - 5 \times 10^{-5}$

Source: DRASTIC data base accessed through GEMS

Table 2.1.F. Upper Bound Estimates of Well Concentrations Based on Solubility Limits of TCDD and TCDF

	TCDD	TCDF	Source
Solubility limit (ug/l)	0.02	4.33	(a)
Recharge rate (cm/yr)	38	38	(b)
Landfill area (cm^2)	2.5×10^9	2.5×10^9	(c)
Total recharge (cm^3/yr):	1×10^{11}	1×10^{11}	(b)
Maximum cont. loading (ug/yr):	2×10^6	4×10^8	
Aquifer depth (m):	3	3	(b)
Aquifer width:	infinite	infinite	(b)
Eff. porosity (unitless):	0.2	0.2	(b)
Hydr. conductivity (m/hour):	41.7	41.7	(b)
Hydraulic gradient (unitless):	0.01	0.01	(b)
K_D (m^3/kg):	2	7×10^{-3}	(d)
Bulk density of soil (kg/m^3):	2,000	2,000	(b)
Longitudinal dispersivity (m):	20	20	(e)
Lateral dispersivity (m):	7	7	(e)
Vertical dispersivity (m):	1	1	(e)
Steady state concentration (ug/l):	3×10^{-9}	7×10^{-7}	(f)
Years to reach steady state:	9,000	32	(f)
Water ingestion (l/day):	2	2	
Absorption from water (unitless):	1	1	
Average body weight (kg):	70	70	
Cancer slope factor (mg/kg/day^{-1})	2.7×10^{-5}	2.7×10^{-4}	
Max cancer risk ($lifetime^{-1}$):	3×10^{-5}	5×10^{-4}	(g)

Notes:

(a) TCDD solubility from Marple et al. (1986), TCDF solubility calculated with CHEMEST

(b) From Estimating Exposures to 2,3,7,8-TCDD, U.S. EPA (1988a)

(c) I [illegible] 04 Mill Study

(d) T [illegible] K_D derived from Jackson (1985), TCDF K_D from CHEMEST calculation. Both estimates assume that fraction of organic carbon in aquifer is 0.02 percent, after U.S. EPA (1988a).

(e) Within ranges suggested by Yeh (1980) for sand

(f) Estimated with AT123D (Yeh, 1980), with assumptions listed above

(g) Equals [water conc. x (1×10^{-3} mg/ug) x ingestion x absorption / body weight] x cancer slope factor

Table 2.1.G. Assumptions and Parameter Values for a Typical Individual - Landfill: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate loading to aquifer	SESOIL	SESOIL	Equilibrium partition model	High estimate assumes that water concentration is in equilibrium partition with highest sludge concentration.	Bonazountas and Wagner (1984); this analysis.
Depth of cover (cm)	10	10	0	High risk estimate based on landfill without cover	U.S. EPA (1988).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Model used for transport through saturated zone	AT123D	AT123D	AT123D		Yeh (1984); U.S. EPA (1988).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Distance to aquifer (m)	3	3	0	Assumes 6 meter depth to water table. For best estimate scenario, sludge layer extends to 3m below landfill surface, but contaminants and organic carbon are distributed throughout 6m landfill depth	DRASTIC database.
Aquifer medium	Sand and gravel	Sand and gravel	Silty sand	Most common aquifer medium reported in DRASTIC data base for counties containing landfills. See Table 3.3.	
Depth of aquifer	100	100	10		
Width of aquifer (m)	Infinite	Infinite	500		

Table 2.1.G. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Distance to model wells (m)	200 1200 3000	200 1200 3000	200 1200 3000	Midpoints of ranges listed below.	
Distances represented (m)	0-400 400-2,000 2,000-4,000	0-400 400-2,000 2,000-4,000	0-400 400-2,000 2,000-4,000		
Exposed populations				Estimated from density of populations drinking groundwater in each county with a landfill. Low and high risk estimates are minus 50 and plus 100 percent.	Statistical Abstracts; National Well Water Association data; FRDSPWS (GEMS).
0-400 m	125	242	500		
400-2000 m	3,000	5,813	12,000		
2000-4000 m	10,000	18,188	40,000		
Decay	0	0	0	No decay rate available for TCDD or TCDF in groundwater.	
Effective porosity of aquifer medium	0.25	0.25	0.1	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	10	10	1	"Best estimate" is appropriate for productive sand and gravel aquifer; "high risk" estimate appropriate for silty sand	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	1%	Typical value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	10	Within range of "typical" values reported for sand or silt. Low-risk and best estimate values equal approx. 1/10 distance to nearest receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 2.1.G. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Transverse dispersivity (m)	7	7	1	Within range of "typical" values reported for sand or silt. 1/3 and 1/20 of longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Vertical dispersivity (m)	1	1	1	Within range of "typical" values reported for sand.	Yeh (1980).
TCDD K_D in aquifer	10,000	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.

Table 2.1.H. Assumptions and Parameter Values for the Most Exposed Individual - Landfill: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate loading to aquifer	SESOIL	SESOIL	Equilibrium partition model	High estimate assumes that water concentration is in equilibrium partition with highest sludge concentration.	Bonazountas and Wagner (1984); this analysis.
Depth of cover (cm)	10	10	0	High risk estimate based on landfill without cover	U.S. EPA (1988).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Model used for transport through saturated zone	AT123D	AT123D	AT123D		Yeh (1984); U.S. EPA (1988).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Distance to aquifer (m)	3	3	0	Assumes 6 meter depth to water table. For best estimate scenario, sludge layer extends to 3m below landfill surface, but contaminants and organic carbon are distributed throughout 6m landfill depth	DRASTIC database.
Aquifer medium	Sand and gravel	Sand and gravel	Silty sand	Most common aquifer medium reported in DRASTIC data base for counties containing landfills. See Table 3.3.	
Depth of aquifer	100	100	10		
Width of aquifer (m)	Infinite	Infinite	500		

Table 2.1.H. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Distance to model well (m)	200	200	200		
Decay	0	0	0	No decay rate available for TCDD or TCDF in groundwater.	
Effective porosity of aquifer medium	0.25	0.25	0.1	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	10	10	1	"Best estimate" is appropriate for productive sand and gravel aquifer; "high risk" estimate appropriate for silty sand	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	1%	Typical value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	10	Within range of "typical" values reported for sand or silt. Low-risk and best estimate values equal approx. 1/10 distance to nearest receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 2.1.H. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Transverse dispersivity (m)	7	7	1	Within range of "typical" values reported for sand or silt. 1/3 and 1/20 of longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Vertical dispersivity (m)	1	1	1	Within range of "typical" values reported for sand.	Yeh (1980).
TCDD K_D in aquifer	10,000	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.

organic carbon content of the soil. The conservative estimate of low organic carbon content through the entire soil column will tend to over predict actual leachate concentrations.

Based on a "worst case" scenario and the assumption of equilibrium partitioning, maximum dissolved leachate concentrations are estimated to be 2 x 10^{-7} ug/l and 1 x 10^{-3} ug/l for TCDD and TCDF, respectively. These concentrations represent approximately 0.001 percent of the solubility limit for TCDD, and 0.03 percent for TCDF. Results from SESOIL (with "best estimate" input parameters) predict lower concentrations: 2 x 10^{-8} ug/l for TCDD, and 3 x 10^{-5} ug/l for TCDF, or 0.0001 and 0.001 percent of their respective solubility limits. These loadings are used as input for the AT123D model to predict TCDD and TCDF concentrations in an aquifer at specified down-gradient locations.

Data Sources and Model Inputs for Estimating Transport through the Saturated Zone

Table 2.1.H lists the parameter values used for AT123D simulations to predict contaminant transport through the aquifer. As shown by Table 2.1.E, sand and gravel appears to be the most common aquifer medium in counties containing pulp and paper sludge landfills. This analysis therefore selects values for hydraulic conductivity, porosity, and bulk density that are appropriate for this medium, based on ranges reported in Freeze and Cherry (1979) and Yeh (1980). For "best estimate" simulations, the source is assumed to be a square with edges of 350 meters. The configuration of the "worst case" source is based on a landfill of 60 acres, idealized by a square with edges of 500 meters in length. For "high risk" simulations, the aquifer is described by the physical characteristics of silt, as shown in Table 2.1.H. For all simulations, well are assumed to be located 200, 1,200, and 3000 meters from the source. To avoid problems with time step selection for the AT123D model, separate simulations were performed for each of the distances modeled.

As shown in Tables 2.1.A and 2.1.B, the organic carbon distribution coefficients (K_{oc}) for TCDD and TCDF are assumed to be 1 x 10^{7} and 3.5 x 10^{6} respectively, and the aquifer medium is assumed to consist of only 0.1 percent organic carbon. With these assumptions, retarded darcy velocities of TCDD and TCDF are only 7 x 10^{-6} m/hr and 2 x 10^{-3} m/hr respectively, so that steady state concentrations at the most distant well are not attained for thousands of years (for TCDD) and about 150 years (for TCDF) after the contaminants first enter the aquifer beneath the landfill site. The aquifer is assumed to be described by a 1 percent gradient, a 100 meters per day hydraulic conductivity, and an effective porosity of 0.2. These values are appropriate for a sand and gravel aquifer according to Freeze and Cherry (1979). Based on these and other input parameters listed in Table 2.1.F, this analysis uses the AT123D model to estimate "steady state" concentrations of TCDD and TCDF at the test wells. Although the hydrophobic quality of TCDD (and to a lesser extent of

TCDF) retards its travel through the saturated zone, steady state results (as calculated by the AT123D model) are insensitive to retardation of the two chemicals as a result of partitioning between liquid and solid phases. Based on these assumptions, the AT123D model predicts the steady state concentrations listed in Table 2.1.I.

To estimate potential human exposure and risk from well-water contamination requires additional assumptions about individual behavior and the sizes of exposed populations. The methods outlined above suggest that approximately 250 persons live down-gradient within 400 meters of a facility, 5,800 live between 400 and 2,000 meters, and 18,000 live between 2,000 and 4,000 meters.

2.1.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources

Where pulp and paper sludge is deposited in uncovered landfills, particles of sludge or soil from the landfill surface can be transported by erosion to nearby lakes or streams. If humans consume water from these lakes or streams, they may be exposed to TCDD and TCDF from the landfilled sludge. This Section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health. The methodology consists of three general steps. First, based on sludge concentrations of TCDD and TCDF, local topography, land use and other factors, it ertimates contaminant concentrations in sediments and surface water. Second, it uses these estimated concentrations, assumptions about individual ingestion of drinking water, and assumptions about the bio-availability and the cancer slope factor of TCDD and TCDF, to estimate individual health risks for humans potentially exposed. Third, it combines these results with estimates of the size of exposed populations to derive estimates of total human health risks in the U.S. population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Details of the methods used for these calculations are presented in Appendix B. In general, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the landfill. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the landfill surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases, based on the assumption of equilibrium partitioning between the two phases.

Table 2.1.I. Estimated Groundwater Concentrations At Selected Distances from Model Landfill

	200 meters (ug/l)	1,200 meters (ug/l)	3,000 meters (ug/l)
High Risk Estimate[a]			
TCDD	1×10^{-11}	6×10^{-12}	4×10^{-12}
TCDF	7×10^{-8}	4×10^{-8}	3×10^{-8}
Best Estimate[b]			
TCDD	8×10^{-14}	3×10^{-14}	2×10^{-14}
TCDF	1×10^{-10}	6×10^{-11}	3×10^{-11}

Notes:

(a) Combines results from equilibrium partition model with AT123D results and "high-risk" assumptions.

(b) Combines results from SESOIL witn AT123D results and "best estimate" assumptions.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Drinking Water from Surface Water Sources

Water concentrations are multiplied by human consumption of water and a bio-availability factor to yield the estimated human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$Dose_w = \frac{C_w \, Q_w \, BA_w}{BW}$$

where:

C_w = Concentration of contaminant in water (mg/liter)

BA_w = Bio-availability of TCDD or TCDF from ingested water (unitless)

BW = Human body weight (assumed to be 70 kg)

Q_w = Individual's consumption of water (liters/day)

$Dose_w$ = Dose of contaminant from consumption of water (mg/kg/day)

Methods for Estimating the Size of Exposed Populations

The population exposed to contaminated water is estimated by multiplying the area of the drainage basin above each SMA drainage point by the estimated population density of that area. This estimated population is then multiplied by the fraction of the population that takes its drinking water from surface supplies:

$$PE_w = A_B \, PD \, PSW$$

where:

PE_w = Population exposed to contaminated water

A_B = Area of the drainage basin (ha)

PD = Population density for region of landfill (persons/ha)

PSW = Percent of population served by surface water

Data Sources and Model Inputs for Estimating Soil Contaminant Concentrations

In this analysis, landfills are assumed to be uncovered; reliable data are not at this time available for management practices at pulp and paper sludge landfills. For a landfill without soil cover, initial soil concentrations are assumed to equal sludge concentrations. "Best estimate" and "low risk" calculations for typical individuals use the average sludge concentration reported by the 59 landfills. "High risk" typical individual estimates and the MEI scenarios are based on the highest reported sludge concentrations. Sludge concentrations were taken from the "104 Mill Study" (U.S. EPA, 1989).

Data Sources and Model Inputs for Estimating Sediment Contaminant Concentration

As explained in Appendix B, the parameters necessary to calculate sediment concentration (before partitioning) from soil concentration are: site area, site sediment delivery ratio, drainage area, drainage area sediment delivery ratio, and the Universal Soil Loss Equation parameters.

The soil concentrations are discussed above. The landfills are assumed to be 12 hectares in the typical "low risk" and "best estimate" scenarios and 24 hectares in the typical "high risk" and the MEI scenarios. These areas are suggested by U.S. EPA (1985).

The calculation for the SMA sediment delivery ratio, as shown above, depends on the overland distance between the SMA and the water body. Based on U.S. EPA (1988b), the distance to surface water is assumed to be 152 meters in the typical "low risk" and "best estimate" scenarios and 30 meters in the typical "high risk" and MEI scenarios.

The watershed sediment delivery ratio is dependant on the area of the watershed. The "best estimate" and "high risk" typical individual estimate assume the water body receiving SMA runoff is a major stream with a watershed area of 5,000 square miles. This estimate is based on U.S. EPA Geographic Exposure Modeling System (GEMS) estimates of drainage area for major streams (U.S. EPA, 1989c). The "low risk" typical individual estimate assumes that the receiving water body is a smaller tributary with a watershed area of 500 square miles. The watershed in the MEI scenarios is assumed to be 10,000 acres (approximately 40 square miles). This area corresponds to a relatively small stream (U.S. EPA 1988a).

The cover management, "C", and support practice, "P", variables from the USLE equation are determined as a ratio of SMA to watershed. This analysis assumes that landfills are surrounded by pasture land. "C" values on permanent pasture, range, and idle land range from approximately 0.3% to 45%, with an average of approximately 10% (Science and Education Administration, 1978). In other words, the approximate average soil loss from pasture under specified conditions is 10 percent of the corresponding loss from clean-tilled, continuous fallow. In the typical "low risk" and "best estimate" scenarios, the landfills are assumed to be 90 percent covered with vegetation, resulting in a "C" ratio of 1.1:1. The typical "high risk" and the MEI scenarios more conservatively assume that the landfills have no vegetative cover. This assumption results in a "C" ratio of 10:1. All scenarios conservatively assume that no support practices are in place since insufficient information on support practices is available. Therefore the "P" ratio in all scenarios is 1:1.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the partition coefficient between water and organic carbon, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the partition coefficient between sediment and water. The Koc value for TCDD used in this analysis is 1×10^7 (Jackson, 1985 in EPA, 1987c). The Koc value for TCDF is 3.5×10^6 (CHEMEST procedure in GEMS, U.S. EPA, 1989c). The organic carbon content of the sediment is assumed to be 0.04 in the "low risk" typical individual estimate, 0.01 in the typical individual and MEI "best estimate", and 0.001 in the "high risk" typical individual and MEI estimate (U.S. EPA, 1988a).

Data Sources and Model Inputs for Estimating Human Dose

Table 2.1.J lists assumptions and input parameters used for estimating typical exposure through pathways associated with surface runoff. Table 2.1.K lists assumptions and input parameters for the most exposed individual. Individual water consumption is assumed to be 2 liters per day (U.S. EPA, 1988b). The bio-availability of ingested water is assumed to be 100 percent (EPA, 1989c).

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

As previously discussed, sizes of exposed populations are estimated by multiplying estimated watershed area by estimated population density. To accurately assess population exposed it is necessary to know the stream into which the SMA runoff drains, the dilution and dispersion pattern of the contaminant, and the patterns of water withdrawal from the water body. In the absence of this site-specific information, the size of the exposed population is estimated as follows.

The typical "best estimate" scenario assumes that the receiving stream for each landfills is a major stream with a 5,000 square mile watershed area. It is further assumed that the size of the exposed population increases with stream size, and that stream size increases with drainage area i.e.,

Table 2.1.J. Assumptions and Parameter Values for a Typical Individual - Landfills: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
SMA Soil Cover	None	None	None		
SMA Vegetative Cover	90%	90%	None		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
"C" ratio	1.1:1	1.1:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	
"P" ratio	1:1	1:1	1:1	Assumes no support practices	
Distance from site to surface water (meters)	152	152	30		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Drainage Area (ha)	129,500	1,295,000	1,295,000	"Best" and "high" scenarios assume the sites drain into a major waterway. The "low risk" scenario assumes the sites drain into a smaller tributary.	
Percent Organic Carbon in Soil	0.04	0.01	0.001		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2	2		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)

Table 2.1.J. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100	100		
Fish to sediment ratio					Low and best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
- Dioxin	.0967	.0967	10		
- Furan	.1538	.1538	10		
Fish consumption (grams/day)	6.5	6.5	16	Includes fresh water and estuarine fish and shellfish.	Low and best: U.S. EPA "Estimating Exposure 2,3,7,8, TCDD" (1988), OHEA, Exposure Assessment Group (Draft) High: U.S. EPA "Risk Assessment for Dioxin Contamination Midland, Michigan," April, 1988
Percent of fish consumed by the exposed population that is contaminated	100	100	100		
Human Absorption:					U.S. EPA memo from Dioxins in Paper Work Group. "Bio-availability of Dioxins in Paper Products," 6/23/89
Water:	100	100	100		
Fish:	85	90	95		

Table 2.1.J. (cont.) Assumptions and Parameter Values for a Typical Individual - Landfills: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5	0.5		U.S. EPA memo, "Bio-concentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	124	124	124		U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	49	49	49		U.S. Geological Survey (1985)
Sportfisher fish consumption (grams/day)	N.C.	48	48		Humphrey (1983) in U.S. EPA (1988)
Percent of population consuming fish at Sportfisher level	N.C.	3.7	3.7		US Department of Agriculture, "National Food Consumption Survey, 1977-1978"

Notes: N.C. = Not calculated.

Table 2.1.K. Assumptions and Parameter Values for the Most Exposed Individual - Landfills: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
SMA Soil Cover	None	None		
SMA Vegetative Cover	None	None		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group (Draft)
"C" ratio	10:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	
"P" ratio	1:1	1:1	Assumes no support practices	
Distance from site to surface water (meters)	30	30		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Drainage Area (ha)	4047	4047	Assumes that the SMA drains into a relatively small stream.	U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Percent Organic Carbon in Sediment	0.01	0.001		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)

Table 2.1.K. Assumptions and Parameter Values for the Most Exposed Individual - Landfills: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Percent of water consumed that is contaminated	100	100		
Fish to sediment ratio (whole body)				Best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA, (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, ' Exposure Assessment Group (Draft)
Dioxin	.0967	10		
Furan	.1538	10		
Fish consumption (grams/day)	100	100		Humphrey (1976) in EPA (1988), "Risk Assessment for Dioxin Contamination. Midland, Michigan."
Percent of fish consumed that is contaminated	100	100		
Human Absorption:				
Water:	100	100		U.S. EPA memo from Dioxins in Paper Work Group. "Bioavailability of Dioxins in Paper Products," 6/23/89
Fish:	95	95		
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA (1989) memo, "Bioconcentration Factors for 2,3,7,8-TCDD and TCDF," August.

the larger the drainage area, the more people are likely to use the stream for a drinking water supply. To capture this relationship, the size of the exposed population is approximated by the number of persons expected to live in the area of the drainage basin containing each landfill. The area of each basin (assumed to be 5,000 square miles for all landfills in the "best" estimate) is multiplied by the average population density in the regions through which the waterway flows. Population density is determined by averaging populations for the regions of the United States within which a landfill is located and dividing by the area for these regions. Regional populations were considered rather than state populations because the contaminated waterways are not constrained by state boundaries. The average population density for regions where landfills are sited is estimated as 124 people per square mile (U.S. Department of Commerce, 1987).

Only a portion of this population will rely on surface water for their drinking water. The estimated population exposed is therefore reduced by multiplying by the national average percentage of population served by surface water, obtained from the U.S. Geological Survey (USGS, 1985).

This analysis assumes that the entire exposed population ingests water at concentrations estimated at the "point" of entry of the SMA runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles in the "best" estimate, this assumption is conservative, and will tend to overstate exposure and risk. In reality, dilution and dispersion of the contaminant will have occurred before much of the population is exposed. However, in the absence of additional site-specific information, it was not possible to calculate exposure more exactly.

One test of the reasonableness of the analysis' assumption about the size of the exposed population is to compare the amount of drinking water assumed to be withdrawn from the contaminated stream with the stream's flow rate. If the stream can not supply the quantity of water that the analysis assumes is ingested then the assumptions must be reexamined.

The "best" risk estimate for the population assumes that a water body with a drainage area of 5000 square miles is contaminated. A water body with this drainage area would be a relatively major stream, receiving runoff from an area approximately 70 by 70 miles. Several streams located near paper mills have a drainage area of a few thousand square miles. For example, Raccoon Creek at Granville, OH has a drainage area of 8,270 square miles (U.S. EPA, 1989d).

The U.S. Geological Survey has used regression analysis to study the relationship between a stream's drainage area and its mean annual flow rate. On a national scale, USGS found drainage area to be the most significant variable influencing flow rate; other variables, particularly average annual precipitation, were also sometimes significant (personal communication, USGS). Since annual precipitation varies substantially throughout the United States, drainage area alone is not a precise predictor of stream flow. However, the general relationship between drainage area and stream flow can be estimated for regions of the country.

For regions east of the Mississippi, the range of stream flows associated with a drainage area can be approximated from the following equations (personal communication, USGS).

Low Estimate

MAF = DRA

High Estimate

MAF = 1.5 DRA

where:

DRA = Drainage area (square miles), and
MAF = Mean annual flow rate (cubic feet per second or cfs).

Regions west of the Mississippi will show greater variability in stream flows with relationship to drainage area, with extremely arid areas approaching zero cubic feet per second per square mile of drainage area. However, moderately arid regions are likely to exhibit a relationship between stream flow and drainage area that can be approximately represented by the following equation.

MAF = 0.5 DRA

Using these formulas to predict mean annual flow rates for a stream with a 5,000 square mile drainage area yields 5,000 to 7,500 cfs in relatively humid (generally eastern) states and about 2,500 cfs in relatively arid (generally western) states. Converting to liters per year, the mean flow rates are 4.5×10^{12} to 6.7×10^{12} liters/year for humid states. Arid states have a mean annual stream flow rate of approximately 2.2×10^{12} liters per year associated with a stream with a 5,000 square mile drainage area.

The flow rate for a stream with a 5,000 square mile drainage area can be compared with the quantity of drinking water assumed to be withdrawn from the stream to evaluate the feasibility of assumptions about the size of the exposed population. To estimate drinking water withdrawals, the exposed population is multiplied by the quantity of water consumed per person. The analysis assumes that a person consumes 2 liters of water per day. The population exposed near landfills depends on the population density of the regions of the country in which the SMA's are located. The exposed population also depends on the percent of the population that receives its drinking water from surface water. The population exposed to contaminated water is estimated to be 61 people per square mile of drainage area.

A comparison of water withdrawals and stream flows for land application sites will have a relatively large population withdrawing water. The water withdrawals will be from a stream with a relatively high stream flow:drainage area ratio, since land application sites are located in the eastern United States. Water withdrawal for drinking is calculated by multiplying a 5,000 square mile drainage area by 61 exposed people per square mile. This yields an exposed population of 305,000 people. Total surface water withdrawal for drinking, at 2 liters per person per day, is 2.2×10^8 liters/year. Comparing the water withdrawals to the stream flow shows that less than 0.003 percent of the predicted stream flow is withdrawn for human consumption.

It is likely that the population receiving its drinking water from contaminated surface water will receive the remainder of water for domestic uses from this same source. Therefore, it is also informative to compare total water withdrawn for domestic use with the stream flow. Average domestic water use is 78 gallons, or 295 liters, per person per day (USGS, 1985). Two hundred and ninety-five liters per day multiplied by a population of 305,000 people equals annual domestic use of 3.3×10^{10} liters per year. Estimated total domestic use as a percentage of stream flow is therefore less than one percent.

In evaluating the plausibility of these calculations, one should note that 77% of water used domestically is return flow (USGS, 1985). This means that the water reaches a ground- or surface-water source after release from the point of use and thus becomes available for further use. The above discussion suggests that the assumptions in this analysis about the size of populations exposed to surface water are plausible.

2.1.4 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Where pulp and paper sludge is deposited in uncovered landfills, particles of sludge or soil from the landfill surface can be transported by erosion to nearby lakes or streams. If the sludge contains TCDD or TCDF, then those particles can carry these contaminants to the surface water bodies. Fish living in the lakes or streams can take up sludge contaminants into their tissues; if humans then consume those fish, they can be exposed.

This Section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health. The methodology is quite similar to that discussed in Section 2.1.3, in that both methodologies begin by estimating sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from landfills. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 2.1.3, and uses fish to sediment bio-concentration factors and estimates of human fish consumption contaminant doses to humans. The last step in the methodology involves estimating the sizes of exposed populations, combining these results with estimates of individual dose and health risk to derive total health risks to the entire exposed population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Methods used for these calculations are described in detail in Appendix B. In summary, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the landfill. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the surface of the landfill, the methodology derives estimates of the concentration of contaminants in the sediment. These sediment concentrations can then be used to estimate contaminant concentrations in the tissues of fish.

Methods for Estimating the Concentration of TCDD and TCDF in Fish Tissues, as a Function of Sediment Concentrations

Methods for estimating contaminant concentrations in fish are discussed in detail in Appendix B. Based on the assumption that sediment concentrations are the best predictor of fish concentrations of hydrophobic compounds like TCDD and TCDF, the methodology uses empirical fish to sediment bio-concentration factors to estimated concentrations of contaminant in freshwater fish as a function of concentrations in stream or lake sediment. As explained in Appendix B, the concentrations of TCDD and TCDF in the muscle tissues of fish (consumed by humans) are considered to be fifty percent lower than the whole body concentrations of these contaminants.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Fish

Estimated contaminant concentrations in fish tissue are multiplied by an estimated amount of fish consumed daily and a bio-availability factor to yield human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$\text{Dose}_F = \frac{C_F\, Q_F\, BA_F}{BW}$$

where:

BA_F = Bio-availability of TCDD or TCDF from fish (unitless)

BW = Human body weight (assumed to be 70 kg)

C_F = Concentration of contaminant in fish tissue (mg/g)

Q_F = Individual's daily fish consumption (g/day)

Dose_F = Dose of contaminant from consumption of fish (mg/kg/day)

Methods for Estimating the Size of Populations Exposed to TCDD and TCDF through Ingestion of Fish

The population exposed to fish containing TCDD and TCDF is estimated by multiplying the area of the drainage basin containing each facility by an estimated population density of the regions containing the SMA's.

$$PE_F = A_B\, PD$$

where:

PE_F = Population exposed to contaminated water

A_B = Area of the drainage basin (ha)

PD = Population density for region of landfill (persons/ha)

Data Sources and Model Inputs for Estimating Soil Contaminant Concentrations

In this analysis, landfills are assumed to be uncovered; reliable data are not at this time available for management practices at pulp and paper sludge landfills. For a landfill without soil cover, initial soil concentrations are assumed to equal sludge concentrations. "Best estimate and "low risk" calculations for typical individuals use the average sludge concentration reported for all of the landfills. "High risk" typical individual estimates and the MEI scenarios are based on the highest reported sludge concentrations. Sludge concentrations were taken from the "104-Mill Study" (U.S. EPA, 1989c).

Data Sources and Model Inputs for Estimating Sediment and Fish Contaminant Concentrations

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 2.1.J for typical individuals and Table 2.1.K for the most exposed individual.

Data Sources and Model Inputs for Estimating Human Dose

A contaminant dose from ingestion of contaminated fish is estimated for three populations: typical individuals, an MEI, and sport fishers. As an input to the dose calculation, consumption of freshwater and estuarine fin fish and shellfish is estimated for these three populations. Numerous studies report quantities of fish consumed by humans but most include marine fish. U.S. EPA has cited 6.5 grams/day as the average freshwater fish consumption (U.S. EPA, 1980, in U.S. EPA 1988a). The Food and Drug Administration (FDA) has estimated 16 grams per day as the upper 90th percentile ingestion rate of freshwater fish in the Great Lakes area (U.S. EPA, 1988b). This analysis assumes fish consumption of 6.5 grams per day for a typical individual in the "low risk" scenario and "best estimate" and a consumption rate of 16 grams per day for the typical individual "high risk" exposure estimate.

Since these overall averages include a large proportion of individuals who eat no freshwater fish at all, particular populations may consume larger quantities. In particular, sport fishers are likely to consume fish at a higher rate than a typical individual. The "best estimate" and "high risk" sport fisher scenarios incorporate the assumptions used in the population "best estimate" and "high risk" scenarios, respectively except they use different rates of fish consumption and a smaller exposed population to reflect the typical behavior of sport fishers. This analysis assumes sport fishers consume 48 grams of fish per day in both the "best estimate" and the "high risk" scenarios. This is the median consumption rate for sport fishers in Michigan reported by Humphrey (1983). The MEI analyses uses the 90th percentile consumption rates of active sport fishers, 100 grams per day, to represent MEI consumption rates (Humphrey, 1976).

Bioavailability rates for the contaminants consumed in fish are taken from U.S. EPA (1989c). TCDD and TCDF are assumed to be 85, 90, and 95 percent bioavailable for "low", "best", and "high" calculations, respectively. Contaminants consumed with fish are assumed to be 95 percent bioavailable in both the "best" and "high" MEI risk estimates.

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

This analysis assumes that all fish are consumed regionally. An alternative would be to assume that the fish are distributed nationally. In that case, the percent of the freshwater fish each person consumes from the contaminated stream might be calculated by calculating the ratio of the drainage area of the contaminated stream to the drainage area of the entire United States. This percentage could then be used as the percent of contaminated freshwater fish consumed by the entire U.S. population. Instead, the current methodology uses drainage area to determine the proportion of U.S. citizens who are exposed to the contaminated water and fish. This population is then assumed to consume 100% of their freshwater fish from the contaminated stream. These two methods will yield similar estimates of total risk to the population since the analysis assumes a linear dose-response relationship.

As previously discussed, sizes of exposed populations are estimated by multiplying the estimated watershed area by the estimated population density. To accurately estimate site-specific populations exposed it is necessary to know the stream into which the SMA runoff drains, the downstream uses of the surface water (e.g., fishing, drinking), and the distribution of the fish that are caught. In the absence of this site-specific information, the size of the exposed population is estimated as follows.

It is assumed that the size of the population exposed will be positively correlated with stream size and that stream size will be positively correlated with drainage area; the larger the drainage area, the more people are likely to receive their drinking water supply from the stream. To quantify this relationship, population exposed is modeled as a function of drainage area. Each unit area of the watershed is multiplied by the average population density for the regions through which the waterways flow to yield population exposed. For landfills, the population density is estimated to be 124 people per square mile.

In the "best estimate" and the "high risk" scenarios for typical individuals, it is assumed that the receiving stream for each SMA is a major stream with a 5,000 square mile watershed area. In the "low risk" estimate for typical individuals, the drainage area is assumed to be one-tenth of this size, or 500 square miles. The drainage area in both MEI scenarios is assumed to be about 40 square miles. This corresponds to a relatively small stream (U.S. EPA, 1988a).

To calculate the sportfisher population exposed to contaminated fish, the total population exposed is first calculated as described above. The percentage of U.S. non-metropolitan households consuming "home produced" fish and poultry is estimated to be 7.1% (U.S. Department of Agriculture

1978). The percentage of these households consuming "home produced" poultry is estimated at 3.4% (U.S. Department of Agriculture 1978). If the populations home-producing poultry and fish do not overlap then 3.7% of the population home-produces fish. To estimate the population consuming fish at the median sportfisher level of 48 grams per day, the total population exposed is multiplied by 3.7%. This calculation assumes that the family of a sportfisher consumes fish at the same rate as a sportfisher.

This analysis assumes that the entire exposed population ingests fish at concentrations appropriate for the "point" of entry of the SMA runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles in the "best" and "high" estimates, this assumption is conservative, and will tend to overstate exposure and risk. In reality, dilution and dispersion of the contaminant would have occurred before much of the population was exposed.

2.1.5 Results

Tables 2.1.L and 2.1.M present human exposure and risk estimates for the four pathways of potential exposure considered for this waste disposal practice. As can be seen from the tables, exposure and risks to the "most exposed individual" from the landfilling of sludge are highest from pathways associated with surface runoff. Estimated risks through these pathways for the MEI are based on an extreme scenario in which runoff from the site reaches a stream of relatively small drainage area, and the MEI is assumed to take drinking water or fish from the most contaminated segment of the stream. Typical risks through surface water pathways are estimated based on the assumption of larger drainage areas, and are considerably lower.

Table 2.1.L. Best Estimate of Human Exposure from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed:	1×10^{-14}	(<0.1)	3×10^{-18}	(<0.1)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed:	3×10^{-14}	(0.5)	4×10^{-16}	(6)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed:	4×10^{-9}	(0.2)	2×10^{-13}	(0.4)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed:	6×10^{-9}	(22)	3×10^{-14}	(43)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from landfills in which sludge is disposed:	6×10^{-9}	(22)	2×10^{-13}	(43)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 2.1.M Best Estimate of Human Health Risk from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

posure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
halation exposure from volatilization om landfills in which sludge is disposed: ercent TCDD)[c]	3×10^{-9} (<0.1)	8×10^{-13} (<0.1)	12,800,000	2×10^{-7} (<0.1)
gestion exposure from drinking groundwater ntaminated by leachate from landfills which sludge is disposed: rcent TCDD)[c]	8×10^{-9} (0.5)	1×10^{-10} (6)	23,810	4×10^{-8} (6)
gestion exposure from drinking surface er contaminated by surface runoff landfills in which sludge is disposed: cent TCDD)[c]	1×10^{-3} (0.2)	5×10^{-8} (0.4)	6,982,000	5×10^{-3} (0.4)
gestion exposure from fish caught in face water contaminated by runoff landfills in which sludge is disposed: rcent TCDD)[c]	2×10^{-3} (22)	7×10^{-9} (43)	14,200,000	1×10^{-3} (43)
stion exposure from fish caught by creational fishing in surface water taminated by runoff from landfills in ch sludge is disposed: rcent TCDD)[c]	2×10^{-3} (22)	5×10^{-8} (43)	527,000	4×10^{-4} (43)

es:

lculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

lculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

culated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

REFERENCES FOR SECTION 2.1

Arthur D. Little Inc. (1987). Exposure and Risk Assessment of TCDD and in Bleached Kraft Paper Products, Prepared for the U.S. EPA Office of Water Regulations and Standards, Washington, DC, Contract No. 68-01-6951, June.

Aller, L., Bennett, T. Lehr, J.H., Petty, R.J. (1985). DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeological Settings, U.S. EPA Office of Research and Development, Ada, Oklahoma, May.

Bonazountas, M., and Wagner, J.M. (1984). "SESOIL" A Seasonal Soil Compartment Model. Arthur D. Little Inc. and DIS/ADLPIPE Inc. for the U.S. EPA Office of Toxic Substances, Contract No. 68-01-5271, May.

Bowers, J.F. et al. (1980). Industrial Source Complex (ISC) Dispersion Model User's Guide (Vol. 1). PB80-133044. U.S. EPA, Research Triangle Park, NC.

Eduljee, G. (1987). Volatility of TCDD and PCB form soil. Chemosphere, Vol. 16, No. 4, pp 907-920.

Enfield, C.G., and Bengtsson, G. (1988). Macromolecular transport of hydrophobic contaminants in aqueous environments, Groundwater, Vol. 26, No. 1, January.

Farmer, W.J., Yang, M.S., Letey, J., and Spencer, W.F. (1980). Land Disposal of Hexachlorobenzene Wastes: Controlling Vapor Movement in Soil, EPA-600/2-80-119, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati.

Freeman, R.A., and Shroy, J.M. (1985). Environmental mobility of TCDD, Chemosphere, Vol. 14, No. 6/7, pp 873-876.

Freeze R.A., and Cherry, J.A. (1979). Groundwater. Prentice Hall, Inc., Englewood Cloffs, NJ.

Helling, C.S., Isensee, A.R., Woolson, E.A., Ensor, P.D., Jones, G.E.C., Plimmer, J.R., and Kearney, P.C. (1973), J. Environ. Quality 2, 171.

Hwang, S.T. (1982). Toxic Emissions from Land Disposal Facilities. Environmental Progress. 1:46-52. February.

Hwang and Falco (1986). Estimation of Multimedia Exposures Related to Hazardous Waste Facilities. In: cohen, Y., ed. Pollutants in a Multimedia Environment. Plenum Publishing Co. New York, NY.

Humphrey, H.E.B., Rice, H.A., and BUDD, M.L. (1976). Evaluation of changes of the level of polychlorinated biphenyls (PCB) in human tissue. Final report to FDA. Michigan Department of Public Health, Lansing, Michigan. Cited in US EPA, April, 1988. Risk Assessment for TCDD Contamination Midland, Michigan. EPA-905-4-88-005. Region V.

Humphrey, H.E.B. (1983). Population studies of PCBs in Michigan residents. D'Itri, F.M., and Kamrin, MA., eds., PCBS\s: Human and Environmental Hazards. Butterworth Publishers, Boston, Pg. 299-310. In: EPA (1988). Risk Assessment for TCDD Contamination Midland, Michigan. EPA-905-4-88-005. Region V.

Jackson, D.R., Roulier, M.H., Grotta, H.M., Rust, S.W., Warner, J.S., Arthur, M.F., and DeRoos, F.L. (1985). Leaching potential of 2,3,7,8-TCDD in contaminated soils, in Land Disposal of Hazardous Waste. In Proceedings of the Eleventh Annual Research Symposium at Cincinnatti, OH, April 9-May 1, 1985. Sponsored by the U.S. EPA Office of Research and Development, Cincinnati, OH. NTIS PB85-196376.

Jury, W.A., Spencer, W.F., and Farmer, W.J. (1984), J. Environ. Quality, 13, 580.

Lyman, W.J., Reehl, W.F., and Rosenblatt, D.H. (1982), Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds, McGraw-Hill Book Company, New York.

MacKay, D., and Yeun, A. (1983). Mass transfer coefficient correlations for volatilization of organic solutes from water. Environmental Science and Technology. 17:211-217.

Mill, T. (1985). Prediction of the Environmental Fate of TetrachloroTCDD, in TCDDs in the Environment, M.A. kamrin, and P.W. Rodgers eds., Hemisphere Publishing Corporation, Washington, 1985.

National Council of the Paper Industry for Air and Stream Improvement (NCASI) (1984). The Land Application and Related Utilization of Pulp and Paper Mill Sludges. National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No. 439, New York, August.

National Council of the Paper Industry for Air and Stream Improvement (NCASI) (1987). Assessment of Potential Health Risks from Dermal Exposure to TCDD in Paper Products. Technical Bulletin No. 534, November, 1987.

Neal, H.A. (1987). Solid Waste Management and the Environment: the Mounting Garbage and Trash Crisis, Prentice-Hall, Englewood Cloffs, NJ.

Podoll, R.T., Jaber, H.M., and Mill, T. (1986). TetrachlorodibenzoTCDD: rates of volatilization and photolysis in the environment. Environ. Sci. Technol. 20(5): 490-2.

Roehl, J.W. (1962). "Sediment Source Areas, Delivery Ratios and Influencing Morphological Factors". Publication 59, International Association of Scientific Hydrology, Commission of Land Erosion. Pg. 202-213.

Science and Education Administration and United States Department of Agriculture in Cooperation with Purdue Agricultural Experiment Station (1978). Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. December.

Science Applications International Corp. (1986). Conversion factors for use in estimating environmental transport of contaminated soil from unregulated disposal sites. Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste. Washington, DC, under EPA contract 68-01-7624.

Schroy, J.M., Hileman, F.D., and Cheng, S.C. (1986). Physical/Chemical Properties of 2,3,7,8-Tetrachlorodibenzo-p-TCDD. In:ASTM Spec. Publ. 891 (Aquat. toxicol. Haz. Assess. 8th Symp.): 409-21.

Springer, C., P.D. Lunney, and K.T. Valsaraj (1984). Emission of Hazardous Chemical for Surface and Near Surface Impoundments to Air. U.S. Environmental Protection Agency, Solid and Hazardous Waste Research Division. Cincinnait OH. Project Number 808161-02, pp. 3-4 to 3-16. December.

U.S. Bureau of the Census (1988). Current Industrial Reports. Washington.

U.S. Department of Agriculture. National Food Consumption Survey 1977-1978. Report No. H-6. Human Nutrition Information Service. NFCS-1977-78.

U.S. Department of Commerce (1987). Bureau of the Census. Statistical Abstract of the United States. 1987.

U.S. EPA (1980). Seafood Consumption Data Analysis. Prepared for the Office of Water Regulations and Standards. Washington, DC. By SRI International under EPA contract No. 68-01-3887.

U.S. EPA (1984). "Ambient water quality criteria for 2,3,7,8-tetrachlorodibenzo-p-TCDD." EPA 440/5-84-007. Office of Water Regulations and Standards. February. In U.S. EPA. (1988). Risk Assessment for TCDD Contamination Midland, Michigan. EPA-905-4-88-005. Region V.

U.S. EPA (1985a). "TCDD Transport from Contaminated Sites to Exposed URE Locations: A Methodology for Calculating Conversion Factors". Final Report. G.W. Dawson, et al. Battelle project management division. Richland, WA. June.

U.S. EPA (1985b). Summary of Data on Industrial Non-Hazardous Waste Disposal Practices. Office of Solid Waste and Emergency Response, Washington, DC. December.

U.S. EPA (1986a). Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup. Office of Health and Environmental Assessment, Washington, DC. EPA 600/6-86-002. NTIS PB86-232774/AS.

U.S. EPA (1987a). The National TCDD Study: Tiers 3, 5, 6, and 7. Office of Water Regulations and Standards, Washington DC. EPA 440/4-87-003.

U.S. EPA (1987b). User's Guide to SESOIL Execution in GEMS. Prepared by General Sciences Corporation, for the Office of Pesticides and Toxic Substances, Exposure Evaluation Division, Contract No. 68-02-4281, November.

U.S. EPA (1987c). Exposure and Risk Assessment of TCDD in Bleached Kraft Paper Products. Prepared for the Office of Water Regulations and Standards by Arthur D. Little, Inc. U.S. EPA Contract No. 68-01-6951. June.

U.S. EPA (1987d). Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) -- Air Emission Models. Office of Air Quality Planning and Standards, Research Triangle Park, NC., EPA-450/3-87-026, December.

U.S. EPA (1988a). Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988). Office of Solid Waste and Emergency Response, EPA 530-SW-88-033, NTIS PB88-232780, Washington, March.

U.S. EPA (1988b). Estimating Exposures to 2,3,7,8-TCDD. Office of Health and Environmental Assessment, EPA/600/6-88/005A. External Review Draft, March.

U.S. EPA (1988c). Report to Congress: Solid Waste Disposal in the United States, Volume 1, April.

U.S. EPA (1988d). "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge" Prepared by Environmental Criteria and Assessment Office, Cincinnati, OH.

U.S. EPA (1988e). Development of a Method for Estimating Exposure from the Disposal of Chemical Substances in Landfills. Office of Toxic Substances, Exposure Evaluation Division, Exposure Assessment Branch. EPA Contract No. 68-02-4254. September.

U.S. EPA (1988f). Risk Assessment for Dioxin Contamination Midland Michigan. APA-905/4-88-005. April.

U.S. EPA (1989a). Memorandum: "OTS/EEB Aquatic Life Hazard Assessment (Including BCF Values) for 'Dioxins in Paper'". Office of Pesticides and Toxic Substances. Washington, D.C. August.

U.S. EPA (1989b). Training Materials for GEMS and PCGEMS, Office of Pesticides and Toxic Substances, January.

U.S. EPA (1989c). Memorandum: "Bioavailability of Dioxins in Paper Products". Dioxins in Paper Work Group. June.

U.S. EPA (1989d). Graphical Exposure Modeling System User Guide. Office of Toxic Substances. March.

U.S. EPA (1989e). 104-Mill Study data, Office of Water Regulations and Standards, July 27, 1989 version.

U.S. Geological Survey (1985). National Water Summary - 1985. Washington, D.C.

Vanoni, Vita A., Editor (1975). "Sedimentation Engineering." Prepared by the ASCE task committee for the preparation of the manual on sedimentation of the sedimentation committee of the hydraulics division. NY, NY.

Yeh, G.T. (1981). AT123D: Analytical Transport One-, Two-, and Three-Dimensional Simulation of Waste Transport in the Aquifer System. Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 1439. March.

2.2 Human Exposure and Health Risks from Disposal of Paper Products in Municipal Landfills

As shown in Table 2.2.A, the U.S. generates about 130 million metric tons of municipal waste per year, of which about 45 million tons, or 36 percent, is pulp and paper. After use, these products can be recycled, incinerated, landfilled, or otherwise disposed. About 30 percent of the paper products generated can be expected to contain TCDD and TCDF. To the extent that humans come into contact with contaminants released from these wastes, risks to human health may result. This analysis considers potential health risks from the disposal of paper products in municipal landfills. Risks from other disposal methods for paper products are being estimated in a separate risk assessment.

Two pathways of potential human exposure to TCDD and TCDF from paper products in municipal landfills are considered:

- Contaminants from the paper are released into leachate within the landfill, and seep into an aquifer beneath the facility. Nearby residents ingest drinking water from the aquifer, and are potentially exposed.

- Contaminants from the paper are released into soil moisture and then volatilize from the landfill site to ambient air. Nearby residents inhale the contaminated air and are potentially exposed.

Human exposure through both of these pathways depends in part on the fraction of each landfill's contents consisting of contaminated paper products. If it is assumed that only bleached paper products contain TCDD or TCDF, then one can estimate the fraction of total disposed paper products likely to contain these contaminants. No information could be found describing the fraction of all paper wastes consisting of bleached kraft. Consequently, it is assumed that the fraction of paper product waste that is bleached kraft is the same as the fraction of paper product production that consists of bleached kraft. To the extent that bleached paper products are exported or recycled at higher or lower rates than other paper products, this assumption may over- or under-predict the fraction of municipal waste consisting of bleached kraft.

As shown in Table 2.2.A, bleached kraft accounts for about 30 percent of all pulp and paper production. If this same fraction applies also to solid wastes, then one would expect bleached kraft to account for about 11 percent of total municipal waste. The further assumption that bleached kraft's contribution to municipal landfills does not differ from its contribution to the total municipal waste stream would imply that bleached kraft accounts for about 11 percent of a typical municipal landfill's contents.

Table 2.2.A. Site and Waste Characteristics for Municipal Landfills Receiving Waste Paper Contaminated with TCDD and TCDF

Parameter	Value	Source
Total municipal solid waste (MSW) (Mg/yr):	1.3×10^8	(a)
Total pulp and paper waste (Mg/yr):	4.5×10^7	(a)
Total bleached kraft paper, paperbd., pulp (Mg/yr):	2.3×10^7	(b)
Bleached kraft as fraction of MSW (percent)	10.7	
Maximum concentration of TCDD in paper (ppt):	36	(c)
Maximum concentration of TCDD in MSW (ppt):	4	(d)
Maximum concentration of TCDF in paper (ppt):	333	(c)
Maximum concentration of TCDF in MSW (ppt):	36	(d)
Area potentially affected for each landfill (ha):	500	(e)
Density of persons using groundwater (persons/ha):	4	(f)
Number of landfills:	9,284	(f)
Maximum size of exposed population (persons):	18,500,000	(g)

Notes:

(a) U.S. EPA (1988a).
(b) Arthur D. Little Inc. (1987).
(c) Highest pulp concentration reported in 104-Mill data (U.S. EPA, 1989)
(d) Includes only contribution from paper.
(e) Conservative assumption, equivalent to 1/4 area of circle with 2.5 km radius.
(f) U.S. EPA (1988c).
(g) Equals (area affected per landfill) x (number of landfills) x (population density)

If so, then the average concentration of paper product TCDD and TCDF in a landfill will be roughly one tenth of the concentrations found in the paper products. The highest reported concentrations for TCDD and TCDF in bleached pulp are 36 ppt and 333 ppt respectively (U.S. EPA, 1989). If these same concentrations are assumed to apply to the pulp and paper products disposed in landfills, then one would expect bleached kraft to contribute about 3.6 μg TCDD and 33.3 μg TCDF per metric ton of total municipal waste in a typical landfill.

To estimate potential human exposure and risks from disposal of waste paper in municipal landfills, this analysis uses a series of conservative assumptions, together with the chemical and physical parameters listed in Table 2.2.B, to estimate contaminant concentrations in air above a landfill, and in ground water beneath it. Details of these calculations are presented in Sections 2.2.1 and 2.2.2.

2.2.1 Volatilization Pathway

Humans can be exposed to potential health risks if TCDD and TCDF volatilize from paper in municipal landfills. An upper-bound estimate of the extent of these risks can be derived by combining consistently conservative assumptions into mathematical models for estimating the rate of emissions from these landfills, and then estimating the extent to which emitted contaminants are diluted before inhalation. Table 2.2.A derived conservative estimates of TCDD and TCDF concentrations in a municipal landfill that might result from the disposal of paper products. Based on these concentrations, and the parameter values listed in Table 2.2.B, this analysis uses a set of equations from U.S. EPA (1986) and Hwang and Falco (1986), as described in U.S. EPA (1988b), to predict emissions from a landfill site. It assumes that emissions from the landfill (in g/m^2/second) are described by:

$$N_a = \frac{2D_iE^{4/3}K_{as}C_{so}}{[\pi \alpha T]^{1/2}} \qquad (2.2.1)$$

where:

$$\alpha = \frac{D_iE^{4/3}}{E + p_s(1-E)/K_{as}} \qquad (2.2.2)$$

$$K_{as} = 41\ H_c/K_D \qquad (2.2.3)$$

Table 2.2.B. Assumptions and Parameter Values - Paper Wastes in Municipal Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).

Table 2.2.B. (cont.) Assumptions and Parameter Values - Paper Wastes in Municipal Landfills: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	4,320	infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	3.5×10^4	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

Notes: NA = Not Applicable.

and:

D_i = the molecular diffusivity of contaminant vapor in air (cm/second),
C_{so} = the initial contaminant concentration in the soil (g/g),
E = effective porosity of soil (unitless),
H_c = Henry's law constant (atm m^3 / mol),
ρ_s = true density of soil (g/cm^3),
K_D = the soil/water partition coefficient (cm^3/g),
K_{as} = the air/soil partition coefficient (mg/cm^3 in air per mg/g in soil),
N_a = rate of emissions from the soil surface ($g/m^2/sec$), and
T = duration of exposure (sec).

U.S EPA (1988b) used a numerical solution of a partial differential equation to determine the reduction in volatile emissions that would be expected following the addition of a soil layer to the top of a landfill. For a 10 to 25 centimeter soil cover, EPA estimated that emission rates were reduced by 75 to 80 percent, given a contaminated layer thickness of 8 feet. It is here assumed that municipal landfills apply such a cover, and that emissions are reduced by 75 percent.

As shown in Table 2.2.B, organic carbon partition coefficients for TCDD and TCDF are assumed to be 1×10^7 and 3.5×10^4 respectively. The contents of the landfill are (conservatively) assumed to be only one percent organic carbon, resulting in K_D estimates of only 1×10^5 and 350 for TCDD and TCDF respectively. For TCDD, the K_D estimate is further reduced to correspond to the lowest reported partition coefficient between TCDD in paper and in liquid or about 2,000 g/g (NCASI, 1984). After adjustment for a 10 to 25 centimeter cover layer, Equations 2.2.1 through 2.2.3 predict emissions at the rate of 2×10^{-17} and 9×10^{-16} for TCDD and TCDF respectively.

As a conservative estimate of ambient air concentrations of these contaminants near the landfill, a box model (U.S. EPA, 1988b) is used to estimate concentrations of contaminant in air above the site:

$$C_a = \frac{Q}{LS\ V\ MH} \qquad (2.2.4)$$

where:

Q = total emissions from site (g/sec),

C_a = the ambient air concentration of TCDD or TCDF at the exposure location (g/m^3),

LS = an equivalent side length of the site perpendicular to the wind (m),

MH = the mixing height before being inhaled by an individual (m), and

V = the average wind speed at the inhalation height (m/s).

U.S. EPA (1988c) reports that 95 percent of all municipal landfills are less than 100 acres (41 hectares) hectares in area. This analysis considers a landfill of 41 hectares, represented as a square of width 640 meters. If the average wind velocity at the site is 4.5 meters per second, then the mixing volume of air within 1.5 meters height above the site (the denominator in Equation 2.1.4) is about 4,290 cubic meters per second. Given total emissions of TCDD and TCDF of 2×10^{-17} and 9×10^{-16} grams per second from the landfill area, the box model predicts ambient air concentrations of about 3×10^{-12} and 9×10^{-11} mg/m^3. Based on assumed inhalation rates of 23 m^3 per day of outdoor air directly above the landfill site, these concentrations would result in upper bound cancer risks beneath 10^{-6}. Because the risks to a most exposed individual for this very conservative "high risk" scenario are low, "best estimate" and "low risk" estimates of risks to both the most exposed individual and to average exposed individuals have not been derived.

2.2.2 Groundwater Pathway

Landfill disposal of paper or paperboard containing TCDD and TCDF may result in human exposure and risk if these contaminants migrate from the landfill to groundwater, and are then transported to nearby drinking water wells. Potential human exposure from a given landfill will depend on:

- the concentrations of TCDD and TCDF in the paper products,
- the amount of bleached paper or paperboard placed in the landfill, relative to other waste sources,
- the total composition of the landfill's waste stream (the presence of solvents, for example, might increase the mobility of TCDD and TCDF from paper products),
- landfill characteristics, including dimensions,
- landfill management practices, including the use of liners and leachate collection systems,

- local weather patterns and hydrogeology, and
- the location of nearby drinking water wells (if any).

Methods

This analysis derives a conservative estimate for possible human health risks associated with TCDD and TCDF migrating from paper in municipal landfills. As shown in Table 2.2.A, the fraction of landfilled municipal solid waste that can be expected to consist of paper products containing TCDD and TCDF is first estimated from assumptions about paper products as a fraction of landfilled waste, and data describing bleached kraft paper products as a fraction of total paper production. Second, estimated concentrations of TCDD and TCDF in the landfill are used to estimate maximum expected concentrations of TCDD or TCDF in leachate leaving each landfill. Third, the AT123D model is used to estimate the extent to which these concentrations are likely to be reduced before the contaminants can be transported through groundwater to drinking water wells. Details of these calculations are presented in Table 2.2.C.

NCASI (1987b) has estimated partition coefficients describing equilibrium relationships between TCDD and TCDF concentrations in paper and expected concentrations in several solvents, including water. Of these, the lowest measured coefficients for both contaminants are observed for a eight percent solution of ethanol. NCASI found that the equilibrium concentration of TCDD and TCDF in an ethanol solution in contact with paper to be at least 2,000 times lower than the dry weight concentrations for these two contaminants in the paper. Assuming that sufficient quantities of ethanol (or equivalent solvents) are available in the typical landfill, and that water (and solvent) percolating through the landfill have sufficient time to reach equilibrium concentrations before leaving the landfill, yields maximum expected leachate concentrations of 2×10^{-3} ng/l of TCDD and 2×10^{-2} ng/l of TCDF, as a result of paper product wastes.

Before human exposure can take place, contaminated water leaving the landfill must pass through any existing soil layers between the landfill and the water table, must enter an aquifer, and must be transported down-gradient to a receptor well. As in Section 2.1.2, this analysis uses the AT123D model to estimate the extent to which contaminant concentrations will be reduced before reaching a nearby well.

U.S. EPA (1988c) reports that 95 percent of all municipal landfills are less than 100 acres (41 hectares) in area. If leachate from the landfill contains TCDD and TCDF at the maximum concentrations just estimated, a 100 acre landfill site with 43 cm/year of recharge would release a maximum loading of 2×10^{-11} kg/hour of TCDD and 1×10^{-10} kg/hour of TCDF to an underlying

Table 2.2.C. Estimation of Maximum Human Exposure and Health Risks From Landfilling of Paper Product Wastes Containing TCDD and TCDF

	TCDD	TCDF	Notes
Max. concentration in paper (ng/kg):	36	333	(a)
Est. average concentration in MSW (ng/kg):	4	36	(b)
Kp = partition coefficient for 8% ethanol (cm^3/g):	> 2,000	2,000	(c)
Max. equilibrium conc. in leachate (ug/l):	2×10^{-6}	2×10^{-5}	(d)
Max. contaminant loading to aquifer (kg/hr):	2×10^{-11}	1×10^{-10}	(e)
Max. contaminant conc. at 200 meters (mg/l):	1×10^{-13}	1×10^{-12}	
Max. individual exposure (mg/kg/day):	3×10^{-15}	3×10^{-14}	(g)
Max. individual exposure (TCDD equivalent, mg/kg/day):	6×10^{-15}		(h)
Percent TCDD:	50		(i)
Human cancer slope factor ($mg/kg/day^{-1}$):	2.7×10^5		(j)
Maximum individual risk ($lifetime^{-1}$):	2×10^{-9}		(k)

Notes:

(a) Maximum reported concentrations in bleached pulp.
(b) Adjusted by 10.7% for other wastes in landfill.
(c) Lowest partition coefficients reported in NCASI (1987).
(d) Estimated from concentration in MSW divided by K_D.
(e) Assumes total recharge of 7×10^7 liters per year.
(f) Calculated by the AT123D model (Yeh, 1980) using assumptions discussed in Section 2.1.2.
(g) Assumes 2 liters per day of water ingestion, 100% absorption, and 70 kg body weight.
(h) Equals [TCDD exposure] + [(1/10) TCDF exposure]
(i) Equals [TCDD exposure] / [TCDD exposure + (1/10) TCDF exposure]
(j) $1.5 \times 10^5 / 0.55 = q^*$
(k) Exposure x q^*

aquifer. For a hypothetical landfill of 410 meters width and length (100 acres), and for an aquifer with characteristics described by the "high risk" scenario in Table 2.2.D, the AT123D model can estimate well concentrations at 200 meters from the edge of the facility. Results are included in Table 2.2.C. As shown in the table, these water concentrations suggest a total TCDD equivalent human dose of about 6×10^{-15} mg/kg/day. These exposure estimates apply to a most exposed individual (MEI) drinking water for an entire lifetime from a well 200 meters from a landfill site, and are equivalent to upper bound individual cancer risks of 2×10^{-9}, of which about 50 percent is attributable to TCDD.

2.2.3 Summary of Results

Tables 2.2.E and 2.2.F summarize risk estimates for the disposal of waste paper in municipal landfills. Based on the above calculations, TCDD and TCDF in waste paper products do not appear to result in significant risks to human health when received by municipal landfills. Using conservative assumptions, Section 2.2.1 estimated that maximum cancer risks to human health from the volatilization of TCDD and TCDF from municipal landfills would be expected to be lower than 1×10^{-6} for a most exposed individual who lives 24 hours per day on the down-wind edge of the landfill. Risks from groundwater contamination appear to be lower still, with cancer risks to the MEI of less than 1×10^{-8}. From these results, which are based on consistently conservative assumptions, it appears that human health risks from TCDD and TCDF in paper products disposed in landfills do not warrant concern.

Table 2.2.D. Assumptions and Parameter Values - Paper Wastes in Municipal Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used for transport through saturated zone	NA	NA	AT123D		Yeh (1984); U.S. EPA (1988).
Results used for exposure estimates	NA	NA	Steady state	Conservative.	
Distance to aquifer (m)	NA	NA	0	Conservative.	
Aquifer medium	NA	NA	Silty sand		
Depth of aquifer	NA	NA	10		
Width of aquifer (m)	NA	NA	500		
Distance to model wells (m)	NA	NA	200		
Decay	NA	NA	0	No decay rate available for TCDD or TCDF in groundwater.	
Effective porosity of aquifer medium	NA	NA	0.1	Appropriate for silty sand. Yeh (1981).	Freeze and Cherry (1979);
Hydraulic conductivity	NA	NA	1	"High risk" estimate appropriate for silty sand.	Freeze and Cherry (1979).
Hydraulic gradient	NA	NA	1%	Typical value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	NA	NA	10	Within range of "typical" values reported for sand or silt.	Yeh (1980).

Table 2.2.D. (cont.) Assumptions and Parameter Values - Paper Wastes in Municipal Landfills: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Transverse dispersivity (m)	NA	NA	1	Within range of "typical" values reported for sand or silt.	Yeh (1980.
Vertical dispersivity (m)	NA	NA	1		Yeh (1980).
TCDD K_D in aquifer	NA	NA	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	NA	NA	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.

Notes: Not applicable.

Table 2.2.E. Best Estimate of Human Exposure from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed:	$<4 \times 10^{-12}$	(16)	$<4 \times 10^{-12}$	(16)
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed:	$<6 \times 10^{-15}$	(53)	$<6 \times 10^{-15}$	(53)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

Table 2.2.F. Best Estimate of Human Health Risk from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<9 \times 10^{-7}$ (16)	$<9 \times 10^{-7}$ (16)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<2 \times 10^{-9}$ (53)	$<2 \times 10^{-9}$ (53)	18,500,000	$<4 \times 10^{-4}$ (53)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

REFERENCES FOR SECTION 2.2

Arthur D. Little Inc. (1987). Exposure and Risk Assessment of TCDD and in Bleached Kraft Paper Products, Prepared for the U.S. EPA Office of Water Regulations and Standards, Washington, DC, Contract No. 68-01-6951, June.

Bowers, J.F. et al. (1980). Industrial Source Complex (ISC) Dispersion Model User's Guide (Vol. 1). PB80-133044. U.S. EPA, Research Triangle Park, NC.

Freeze R.A., and Cherry, J.A. (1979). Groundwater. Prentice Hall, Inc., Englewood Cliffs, NJ.

Hwang, S.T. (1982). Toxic Emissions from Land Disposal Facilities. Environmental Progress. 1:46-52. February.

Hwang and Falco (1986). Estimation of Multimedia Exposures Related to Hazardous Waste Facilities. In: Cohen, Y., ed. Pollutants in a Multimedia Environment. Plenum Publishing Co. New York, NY.

MacKay, D., and Yeun, A. (1983). Mass transfer coefficient correlations for volatilization of organic solutes from water. Environmental Science and Technology. 17:211-217.

National Council of the Paper Industry for Air and Stream Improvement (NCASI) (1984). The Land Application and Related Utilization of Pulp and Paper Mill Sludges. National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin No. 439, New York, August.

National Council of the Paper Industry for Air and Stream Improvement (NCASI) (1987). Assessment of Potential Health Risks from Dermal Exposure to TCDD in Paper Products. Technical Bulletin No. 534, November, 1987.

Neal, H.A. (1987). Solid Waste Management and the Environment: the Mounting Garbage and Trash Crisis, Prentice-Hall, Englewood Cliffs, NJ.

Podoll, R.T., Jaber, H.M., and Mill, T. (1986). Tetrachlorodibenzodioxin: rates of volatilization and photolysis in the environment. Environ. Sci. Technol. 20(5): 490-2.

Springer, C., P.D. Lunney, and K.T. Valsaraj (1984). Emission of Hazardous Chemical for Surface and Near Surface Impoundments to Air. U.S. Environmental Protection Agency, Solid and Hazardous Waste Research Division. Cincinnati OH. Project Number 808161-02, pp. 3-4 to 3-16. December.

U.S. EPA (1985). Summary of Data on Industrial Non-Hazardous Waste Disposal Practices. Office of Solid Waste and Emergency Response, Washington, DC. December.

U.S. EPA (1987c). Exposure and Risk Assessment of TCDD in Bleached Kraft Paper Products. Prepared for the Office of Water Regulations and Standards by Arthur D. Little, Inc. U.S. EPA Contract No. 68-01-6951. June.

U.S. EPA (1988a). Characterization of Municipal Solid Waste in the United States, 1960 to 2000 (Update 1988). Office of Solid Waste and Emergency Response, EPA 530-SW-88-033, NTIS PB88-232780, Washington, March.

U.S. EPA (1988c). Report to Congress: Solid Waste Disposal in the United States, Volume 1, April.

U.S. EPA (1989). 104-Mill Study data, Office of Water Regulations and Standards, July 26, 1989 version.

Yeh, G.T. (1981). AT123D: Analytical Transport One-, Two-, and Three-Dimensional Simulation of Waste Transport in the Aquifer System. Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 1439. March.

2.3 Exposure and Risk from Disposal of Pulp and Paper Sludge in Surface Impoundments

Surface impoundments are defined as facilities in which sludge from pulp and paper mills is stored or disposed on land without a cover layer of soil. For this analysis, it is assumed that sludge contained in such facilities is of higher moisture content than the sludge deposited in landfills, at least in the active phase of the surface impoundment. Twenty facilities in the 104-Mill Study (U.S. EPA, 1989c) report using surface impoundments for their sludge. These facilities receive an estimated 600,000 tons of pulp and paper mill sludge per year, with TCDD concentrations that average about 501 TCDD and 2,087 ppt TCDF. Maximum reported concentrations are 3,800 for TCDD and 17,100 for TCDF.

This analysis estimates human exposure to TCDD and TCDF through four exposure pathways associated with surface impoundments:

- Volatilized TCDD and TCDF are emitted from the impoundment surface. These are transported downwind to nearby areas. Humans inhale the contaminated ambient air, and are exposed.
- Contaminants from sludge placed in the impoundment are dissolved in water seeping through the bottom of the facility. Contaminated water enters an aquifer beneath the impoundment, and flows down-gradient to drinking water wells. Humans withdraw drinking water from the contaminated aquifer and are exposed.
- Surface runoff carries particles of sludge from the surface of the impoundment to a nearby lake or stream. TCDD and TCDF adsorbed to these particles enter the surface water body, and is released to surface water. Humans withdraw surface water for drinking and are exposed.
- Surface runoff carries particles of sludge from the surface of the impoundment to a nearby lake or stream, where the particles are suspended or settle to bottom sediment. Fish absorb and bioconcentrate TCDD and TCDF from the sludge particles. Humans ingest the fish, and are exposed.

Estimation of human exposure and health risks through these pathways requires additional assumptions regarding site characteristics and other parameters; Table 2.3.A lists some of the assumptions used for the typical analysis, while Table 2.3.B lists those used in the MEI analysis. Each of the four exposure pathways listed above will be considered individually in Sections 2.3.1 through 2.3.4. Results will be discussed in Section 2.3.5.

2.3.1 Estimates of Exposure and Risk from Inhalation of Vapors

As discussed in Section 2.1.1, volatilized TCDD and TCDF may be emitted from sludge or contaminated soil in a landfill, and can pass through the pore spaces in a soil cover. Volatile

Table 2.3.A. Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: All Exposure Pathways/

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Number of impoundments per site	3	3	3		U.S. EPA (1985).
Area of each impoundment (acres)	25	25	50	Low and best estimates represent "typical" sizes as reported in U.S. EPA (1985). High estimate is best estimate + 100%.	U.S. EPA (1985).
Depth of impoundment (m)	4	4	6		
Fraction organic carbon in sludge (% dry wt)	40%	25%	14%		Derived from NCASI (1984).
Average sludge concentration TCDD (ppt)	501	501	3,800	Average of reported concentrations.	104-Mill study.
Average sludge concentration TCDF (ppt)	2,087	2,087	17,100	Average and highest reported concentrations in 104-Mill study.	104-Mill study.

Table 2.3.A. (cont.) Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Average quantity of sludge received (DMT/yr)	28,653	28,653	91,250	Average and highest reported quantities.	104-Mill study.
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	57	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	2.12×10^{-6}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 2.3.A. (cont.) Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	57	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	4.1×10^4	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

Table 2.3.B. Assumptions and Parameter Values for the Most Exposed Individual - Surface Impoundments: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Number of impoundments per site	3	3	3		U.S. EPA (1985).
Area of each impoundment (acres)	25	25	50	Low and best estimates represent "typical" sizes as reported in U.S. EPA (1985). High estimate is best estimate + 100%.	U.S. EPA (1985).
Depth of impoundment (m)	4	4	6		
Fraction organic carbon in sludge (% dry wt)	40%	25%	14%		Derived from NCASI (1984).
Sludge concentration TCDD (ppt)	3,800	3,800	3,800	Highest reported concentration.	104-Mill study.
Sludge concentration TCDF (ppt)	17,100	17,100	17,100	Highest reported concentration.	104-Mill study.

Table 2.3.B. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Surface Impoundments: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Quantity of sludge received (DMT/yr)	91,250	91,250	91,250	Highest reported quantity.	104-Mill study.
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	57	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	2.12×10^{-6}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 2.3.B. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Surface Impoundments: All Exposure Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	57	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	4.1×10^4	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

emissions from surface impoundments differ in that they are assumed to be emitted from a liquid surface. Modeling potential exposure to TCDD and TCDF vapor from surface impoundments involves two steps. First, one must estimate the rate at which each contaminant is emitted from the surface of an impoundment facility. Second, one must determine how wind transport of emitted contaminants will affect ambient air concentrations in surrounding areas.

Methods for Estimating Volatile Emissions from Surface Impoundments

Several authors have proposed methods for estimating emissions from liquids contained in surface impoundments. Common to most methodologies is the use of a two-layer resistance model to estimate volatile emissions from a liquid surface (Liss and Slater, 1974; Hwang, 1982; Farino et al., 1982; MacKay, 1985). In general, the methodologies assume that emissions occur by molecular diffusion through non-turbulent, viscous sublayers on either side of the air/liquid interface, and that these two films form the dominant resistances to mass transfer across the interface. If background contaminant concentrations in ambient air are negligible, then emissions (in grams per second) can be described by the equation:

$$Q = K_L A C \tag{2.3.1}$$

where:

$$\frac{1}{K_L} = \frac{1}{k_L} + \frac{RT}{Hk_G} \tag{2.3.2}$$

and:

Q = mass flux from the impoundment (g/sec),

A = area of the impoundment (cm^2),

C = contaminant concentration (g/cm^3),

H = Henry's law constant ($atm\text{-}m^3/mol$),

k_G = the exchange rate for the air-viscous sublayer (cm/sec),

k_L = the exchange rate for the liquid-viscous sublayer (cm/sec),
K_L = overall liquid to air mass transfer coefficient (cm/sec),

R = universal gas constant (8.2×10^{-5} $atm\text{-}m^3/mol\text{-}°K$), and

T = absolute temperature (°K).

As described by Equation 2.3.1, the total rate of emissions from an impoundment can be derived as the product of an overall liquid-to-air mass transfer coefficient, the area of the impoundment, and the concentration of contaminant in the impoundment. The two terms on the right side of Equation 2.3.2 describe resistance to contaminant transfer across the liquid and gaseous sublayers, respectively.

Although use of the two-layer resistance model (Equations 2.3.1 and 2.3.2) is well established, methods differ for estimating k_L and k_G. Several mathematical expressions have been derived for estimating these constants; they differ by the units of measure used, by assumptions concerning the type of surface impoundment involved, and by the inclusion of different theoretical considerations.

The U.S. EPA Office of Air Quality Planning and Standards has developed a mathematical model, CHEMDAT7, to estimate air emissions from hazardous waste treatment, storage and disposal facilities (U.S. EPA 1989b). In preparing their model, they reviewed available methodologies for estimating k_L and k_G, and selected appropriate expressions for each type of surface impoundment and set of conditions. For quiescent impoundments, with average wind speeds of greater than 3.25 m/sec and for which the ratio of width:depth exceeds 51:1, they use the following equations:

Liquid phase (from Springer et al., 1984)

$$k_L = 2.611 \times 10^{-7} U_{10}^{2} [D_w/D_{ether}]^{2/3} \tag{2.3.3}$$

Gas phase (from MacKay and Matasuga in Hwang, 1985)

$$k_G = 0.0958\ U^{0.78} Sc_G^{-0.67} d_e^{-0.11} \tag{2.3.4}$$

$$Sc_G = \frac{u_G}{\rho_G D_a}$$

where:

D_a = diffusivity of the contaminant in air (cm^2/s),

d_e = effective diameter of the impoundment (m),

D_{ether} = diffusivity of ether in water (8.5×10^{-6} cm^2/s),

D_w = diffusivity of the contaminant in water (cm^2/s),

ρ_G = density of air (1.2×10^{-3} g/cm^3),

Sc_G = Schmidt number on gas side,

u_G = viscosity of air (1.81×10^{-4} g/cm-s), and

U_{10} = wind speed at 10 m above liquid surface (m/s).

This analysis follows the methods selected by U.S. EPA (1989b), and uses Equations 2.3.3 and 2.3.4 to estimate k_L for Equation 2.3.1.

Estimation of emissions (Q in Equation 2.3.1) requires additional assumptions for estimating the dissolved concentration of TCDD and TCDF. For example, concentrations of dissolved contaminant may vary with depth in the lagoon or over time. If the contents of the impoundment are well mixed, if sludge is deposited only once, and if no contaminant is lost to other loss processes, then the concentration of TCDD in the impoundment will diminish as a result of continued emissions, according to the equation:

$$C_t = C_0 \exp(-K_L t/L)$$

If sludge is instead deposited regularly in the impoundment, then the dissolved concentrations of TCDD and TCDF may remain constant or increase. Unfortunately, sufficient data are not at this time available for detailed, site-specific modeling of the time path of dissolved contaminant concentrations in existing pulp and paper sludge impoundments. This analysis therefore attempts to approximate concentration and emission estimates based on idealized scenarios.

For a "high" estimate of potential exposure and risk, it is assumed that the impoundment is well mixed, with regular additions of sludge containing TCDD and TCDF in known (dry weight) concentrations. It is assumed that TCDD and TCDF are partitioned at equilibrium between adsorbed and dissolved phases in the impoundment. Define:

$$C_{DW} = \frac{M_{CS} + M_{CW}}{M_S}$$

$$C_W = \frac{M_{CW}}{M_W}$$

$$K_D = \frac{M_{CS}\, M_W}{M_S\, M_{CW}}$$

$$P_S = \frac{M_S}{M_S + M_W}$$

where:

C_{DW} = concentration (dry weight) of contaminant in sludge (ug/g)
C_W = concentration of contaminant in liquid (ug/cm^3)
K_D = soil/water partition coefficient for contaminant (cm^3/g)
M_{CS} = mass of adsorbed contaminant in impoundment (ug)
M_{CW} = mass of dissolved contaminant in impoundment (ug)
M_S = mass of solid contents in impoundment (g)
M_W = mass of liquid in impoundment (g)
P_L = percent liquid in lagoon (g/g) = $1-P_S$
P_S = percent solids in lagoon (g/g)

From these equations it follows that:

$$C_W = \frac{C_{DW}}{K_D + (P_L/P_S)}$$

For all values of P_L and P_S, C_W should not exceed:

$$C_W = \frac{C_{DW}}{K_D} \qquad (2.3.5)$$

Given the high values of K_D estimated for TCDD and TCDF, Equation 2.3.5 should provide a reasonable approximation of C_W for values of P_L likely to be encountered in actual lagoons. Substituting into Equation 2.3.1 yields estimated emissions at time zero:

$$Q = \frac{K_L\, C_{DW}\, A}{K_D} \qquad (2.3.6)$$

Methods for Estimating Wind Transport of Volatile Emissions

Once TCDD or TCDF vapor is emitted from a surface impoundment, it can be transported downwind to nearby residents, resulting in potential human exposure and health risks. As in Section 2.1.1, this analysis uses a Gaussian plume dispersion model to estimate the extent to which air concentrations of TCDD and TCDF will be reduced in the process of wind transport. Calculations are performed by the area source version of the ISCLT (Industrial Source Complex, Long Term) model (Bowers et. al, 1980) maintained in the Graphical Exposure Modeling System, or GEMS (U.S. EPA, 1989a).

The area source version of the model estimates ambient air concentrations at selected locations in a polar grid centered on an area source of emissions and extending 50 kilometers in all directions. It then maps those air concentrations onto actual human populations for the regions involved. Population data are drawn from the 1980 Census, mapped to the level of Census block group and enumeration district. In addition to its simulation of contaminant dispersion in the plume downwind of a landfill site, the model also considers losses of contaminant due to photolysis and other first-order decay processes.

ISCLT performs site-specific exposure calculations for each surface impoundment site under consideration. Because specific information required to estimate emissions of TCDD and TCDF to air at each site was not available, all sites in the inventory are assumed to be of identical size, to contain sludge with the same concentrations of TCDD and TCDF, to use the same management practices, and to emit contaminants at identical rates. As in Section 2.1.1, these assumptions vary between "best estimate" and "high risk" estimates, but are applied consistently across all facilities.

Methods for Estimating Human Exposure and Risk

Based on estimated concentrations of TCDD and TCDF in ambient air, individual exposure and cancer risk are calculated by:

$$I_{RD} = E_D \, q^*$$

where:

$$E_D = \frac{C_D \, I_H \, F_A \, LF}{BW \, LE}$$

and:

BW = average body weight (assumed to be 70 kg),

C_D = estimated air concentration at distance D (mg/m^3),

E_D = average lifetime individual exposure for person residing at distance D (mg/kg/day),

F_A = fraction of contaminant absorbed from inhaled air (unitless, assumed to be 1.0),

I_H = volume of air inhaled daily (assumed to be 23 m^3/day, after U.S. EPA, 1985),

I_{RD} = lifetime individual cancer risk for person residing at distance D ($lifetime^{-1}$),

LE = life expectancy (assumed to be 70 years),

LF = number of years of exposure per lifetime (assumed to be 70 years/lifetime), and

q^* = cancer slope factor for TCDD or TCDF $(mg/kg/day)^{-1}$.

ISCLT provides estimates of population-weighted average concentrations of the TCDD or TCDF in ambient air surrounding all landfill facilities. Aggregate cancer risks are calculated with the following expression:

$$E_{AVE} = \frac{C_{AVE}\, I_H\, F_A\, LF}{BW\, LE}$$

$$R_T = E_{AVE}\, q^*\, POP / LE$$

where:

C_{AVE} = average air concentration of contaminant, computed by weighting each level of contaminant concentration by the number of persons exposed to that level (mg/m^3)

E_{AVE} = population-weighted average exposure for all persons living within 50 km of a pulp and paper sludge landfill (mg/kg/day)

POP = total exposed population

R_T = aggregate cancer risk for exposed population (incremental cancer cases/year)

and all other variables are as described above.

Data Sources and Model Inputs for Estimating Vapor Emissions from Surface Impoundments

Table 2.3.C lists assumptions and input parameters used for estimating typical exposure to vapor emissions from sludge surface impoundments, while Table 2.3.D lists those used for estimating MEI exposures. From the highest reported sludge concentrations of 3,800 ng/kg TCDD and 17,100 ng/kg TCDF, combined with K_D values (from f_{OC}=0.14) of 1.4×10^6 cm^3/g and 5×10^3 cm^3/g, Equation 2.3.5 yields upper-bound dissolved concentrations of 3 ng/m^3 TCDD and 3×10^3 ng/m^3 TCDF in the impoundment. These estimates, together with the values of K_L derived in Equations

Table 2.3.C. Assumptions and Parameters Values for a Typical Individual - Surface Impoundments: Volatilization Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate emissions	Two-phase resistance	Two-phase resistance	Two-phase resistance		U.S. EPA (1987); Springer et al. (1984); Hwang (1982).
Model used to estimate wind transport and human exposure	ISCLT	ISCLT	ISCLT		Bowers et al. (1980); GEMS; U.S. EPA (1984).
Temperature (°C)	25	25	25		
Average wind-speed (m/sec)	4.5	4.5	4.5	Single average windspeed used to estimate emissions. Site-specific windspeeds and direction used for ISCLT calculations.	4.45 m/s = 10 mph, average for 60 U.S. cities from (U.S. EPA, 1988b)

Table 2.3.D. Assumptions and Parameters Values for the Most Exposed Individual - Surface Impoundments: Volatilization Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used to estimate emissions	Two-phase resistance	Two-phase resistance	Two-phase resistance		U.S. EPA (1987); Springer et al. (1984); Hwang (1982).
Model used to estimate wind transport and human exposure	ISCLT	ISCLT	ISCLT		Bowers et al. (1980); GEMS; U.S. EPA (1984).
Temperature (°C)	25	25	25		
Average wind-speed (m/sec)	4.5	4.5	4.5	Single average windspeed used to estimate emissions. Site-specific windspeeds and direction used for ISCLT calculations.	4.45 m/s = 10 mph, average for 60 U.S. cities from (U.S. EPA, 1988b)

2.3.2 through 2.3.4 above, show that rates of TCDD emissions from a sludge surface impoundment are unlikely to exceed 1×10^{-14} g/m^2/sec; rates of TCDF emissions are unlikely to exceed 1×10^{-11} g/m^2/sec. These rates are about two orders of magnitude higher than those calculated for an uncovered landfill in Section 2.1.1. They suggest that approximately 0.2 percent of each year's loading of TCDD and 44 percent of each year's loading of TCDF would volatilize each year from a "worst case" impoundment, if the initial water concentrations could be maintained at levels suggested by Equation 2.3.5.

For comparison, Podoll et al. (1986), estimates a volatilization half-life of 32 days for TCDD in a pond of 200 cm depth. This estimate is based on a version of the two-phase resistance model proposed by Smith et al. (1981), and ignores the effects of possible adsorption of TCDD to solid particles in the pond. With a half-life of 32 days, more that 99.9 percent of the contaminant would volatilize within one year, suggesting an average rate of emissions of 7×10^{-12} g/m^2/sec for a pond receiving 91,250 Mg/year of sludge at a concentration of 3,800 ng/kg. Similarly, a volatilization half life of 12-14 hours can be estimated for TCDF, using the CHEMEST routines available in GEMS. Based on these estimates, a 75 acre pond receiving 91,250 Mg/year of sludge with a TCDF concentration of 17,100 ng/kg would emit 3×10^{-11} g/m^2/sec of TCDF. These estimates are considerably higher than the ones derived above, but ignore the extent to which adsorption would limit emissions.

Data Sources and Model Inputs for Estimating Wind Transport

Most inputs for the ISCLT model were obtained from data bases accessed automatically through GEMS. To run the model, GEMS must be supplied with latitude and longitude coordinates for each town containing a sludge landfill. Based on the assumption that each of three impoundments at an average site covers 24.5 to 50 hectares, each site accounts for a total of 74 to 150 hectares of area (U.S. EPA, 1985). These areas can be idealized by a square of width 857 meters (for "best estimate scenarios), and of 1,225 meters (for "high risk" scenarios). Site locations are represented by latitude and longitude coordinates for the town listed in the 104-Mill Study for each mill reporting the use of a surface impoundment. Meteorological data are taken from the weather station nearest to each site location, and are accessed through GEMS.

As discussed in Section 2.1.1, current literature reports atmospheric half lives for TCDD that range from a lower bound of 58 minutes to several days. "Best estimate" calculations for this pathway assume a atmospheric half life of 3 days for TCDD, high risk estimates assume that atmospheric losses are insignificant. Results from ISCLT suggest that the times of wind transport to exposed populations within 50 km of known surface impoundment sites range from about 10 minutes to four hours, with a population-weighted average of about 42 minutes. If the atmospheric half-life of TCDD is indeed three days, then losses over this time interval will be relatively small. The ISCLT model, as implemented in GEMS, estimates that approximately 7 million persons live within 50 km of a surface impoundment site.

2.3.2 Estimating Exposure and Risk from Ingestion of Drinking Water from Groundwater Sources

If TCDD and TCDF are dissolved in water that seeps from the bottom of a surface impoundment, then these contaminants may be transported to an aquifer beneath the facility. If they are then transported down-gradient by groundwater, then they may reach drinking water wells near the site. Humans who ingest water withdrawn from those wells may be exposed to TCDD and TCDF in their drinking water, and are potentially exposed to health risks. This section outlines the methods used by this analysis to assess the extent of that potential exposure and risk.

Methods for Estimating Seepage Beneath a Surface Impoundment

Estimation of potential groundwater contamination from surface impoundments is similar to that from landfills, with one important difference. If a surface impoundment contains a significant volume of water, drainage from the pond may result in increased recharge and contaminant loading to the underlying aquifer. The extent to which the downward flux of water beneath a site is increased by water from the impoundment will depend on:

- the amount of water in the impoundment,
- whether a natural or synthetic liner is present,
- whether the water content of the impoundment is periodically restored by additional deposits of sludge,
- the extent to which the solids layer on the bottom of the impoundment inhibits water flux out of the impoundment, and
- the hydraulic conductivity of the medium between the impoundment and the water table.

Of course, if aquifer recharge beneath an impoundment significantly exceeds the sum of net precipitation and the annual influx of water from sludge, then the impoundment will soon dry out. A sustained and substantial increase in groundwater recharge beneath an impoundment therefore requires repeated additions of water to an active impoundment.

Movement of TCDD (and to a lesser extent TCDF) through soil is retarded by its high soil/water partition coefficient, as discussed in Section 2.1.2. Given a significant soil layer between the impoundment and the water table, steady-state loadings of these contaminants to groundwater beneath an impoundment may not be reached until many years after the sludge is last placed in the facility. If the active lifetime of the impoundment ends before TCDD and TCDF reach the underlying aquifer, then the water content of a surface impoundment may not result in appreciable increases in the peak or "steady state" loading of sludge contaminants to the aquifer.

Ideally, groundwater contamination beneath a surface impoundment could be modeled separately for the active phase of the impoundment (during which sludge is regularly added to the impoundment and the liquid content of the impoundment is maintained or increased), and the inactive phase of the impoundment (during which no further sludge is added, and the liquid content is decreasing or is at equilibrium with precipitation less evaporation). For lack of sufficient data, the present analysis does not attempt to model these two periods separately, nor to quantify the exact extent to which water in an impoundment will increase recharge (and contaminant loading) to an underlying aquifer. Instead, it bounds exposure and risk estimates between two extreme assumptions. The first ("high risk") version assumes that aquifer recharge beneath an impoundment exceeds net precipitation throughout the exposure period. It assumes the absence of synthetic or natural liners, and that the water in the impoundment is regularly replenished by the disposal of additional sludge. Such a scenario might occur, for example, where an impoundment is used for several decades, and where accumulating sludge is occasionally dredged from the bottom of the impoundment.

The second scenario assumes that the impoundment will be inactive during the period in which maximum loading of TCDD and TCDF to the aquifer takes place. If so, then the resulting loading to groundwater can be calculated with methods identical to those used to estimate groundwater contamination beneath sludge landfills. "Best" estimates of exposure and risk are based on results from SESOIL simulations similar to those described in Section 2.1.2. Assumptions and input parameters for both approaches are listed in Table 2.3.E for the typical exposure assessment, and in Table 2.3.F for the MEI exposure assessment.

Contaminant Concentrations in Seepage Beneath an Impoundment

Contaminant concentrations in a surface impoundment are likely to vary with depth and the age of the impoundment; dissolved concentrations may be highest at the bottom of the impoundment, where sludge has settled and the solids are concentrated. As an upper-bound estimate of water concentrations at the bottom of the impoundment, this analysis follows an approach similar to the one outlined in Section 2.1.2, and assumes that concentrations are unlikely to exceed values suggested by the ratio:

Table 2.3.E. Assumptions and Parameters Values for a Typical Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used for transport through unsaturated zone	SESOIL	SESOIL	Equili-	Low and best estimates assume that long term average recharge to aquifer is not affected by water in impoundment. High estimate assumes recharge limited by hydraulic conductivity in unsaturated zone.	U.S. EPA (1987b).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Model used for transport in aquifer	AT123D	AT123D	AT123D		Yeh (1984); U.S. EPA (1989).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Vertical distance to aquifer (m)	3	3	0	Assumes 6 meter depth to water table	DRASTIC database
Aquifer recharge (cm/yr)	43	43	320	Low and best estimates represent typical recharge rate for areas with surface impoundments. Assumes long-term recharge is not affected by water in impoundment. High estimate assumes recharge increased by water in impoundment, and limited only by hydraulic conductivity.	

Table 2.3.E. (cont.) Assumptions and Parameters Values for a Typical Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Vadose zone medium	NA	NA	Sand & gravel, silt & clay	Most common medium in counties containing surface impoundments.	DRASTIC data base in GEMS.
Hydraulic conductivity of unsaturated zone (m/sec)	NA	NA	1×10^{-7}	Selected value is between ranges typical for sand and for clay. Would result in complete drainage of inactive lagoon within three years.	Freeze and Cherry (1979).
Effective porosity of aquifer medium	0.25	0.25	0.25	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	36	10	10	Appropriate for productive sand and gravel aquifer.	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	1%	"Typical" value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	10	Within range of "typical" values reported for sand. Low-risk and best estimate values equal approx. 1/10 distance to receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Transverse dispersivity (m)	7	7	1	Within range of "typical" values reported for sand. Low risk and best estimate values equal 1/3 longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 2.3.E. (cont.) Assumptions and Parameters Values for a Typical Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Vertical dispersivity (m)	1	1	1	Within range of "typical" values reported for sand.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
TCDD K_D in aquifer	10,000	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.
Distance to model wells (m)	200 1,200 3,000	200 1,200 3,000	200 1,200 3,000	Midpoints of ranges listed below.	
Distances represented (m)	0-400 400-2,000 2,000-4,000	0-400 400-2,000 2,000-4,000	0-400 400-2,000 2,000-4,000		
Exposed populations					
0-400 m	20	41	80	Best estimate is based on density of persons drinking wellwater in each relevant county. Low- and high-risk estimates are minus 50 and plus 100 percent.	
400-2,000 m	500	978	2,000		
2,000-4,000 m	1,500	3,055	6,000		

Notes: NA = Not Applicable.

Table 2.3.F. Assumptions and Parameters Values for the Most Exposed Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Model used for transport through unsaturated zone	SESOIL	SESOIL	Equili-	Low and best estimates assume that long term average recharge to aquifer is not affected by water in impoundment. High estimate assumes recharge limited by hydraulic conductivity in unsaturated zone.	U.S. EPA (1987b).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Model used for transport in aquifer	AT123D	AT123D	AT123D		Yeh (1984); U.S. EPA (1989).
Result used for exposure estimates	Steady state	Steady state	Steady state		
Vertical distance to aquifer (m)	3	3	0	Assumes 6 meter depth to water table	DRASTIC database
Aquifer recharge (cm/yr)	43	43	320	Low and best estimates represent typical recharge rate for areas with surface impoundments. Assumes long-term recharge is not affected by water in impoundment. High estimate assumes recharge increased by water in impoundment, and limited only by hydraulic conductivity.	

Table 2.3.F. (cont.) Assumptions and Parameters Values for the Most Exposed Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Vadose zone medium	NA	NA	Sand & gravel, silt & clay	Most common medium in counties containing surface impoundments.	DRASTIC data base in GEMS.
Hydraulic conductivity of unsaturated zone (m/sec)	NA	NA	1×10^{-7}	Selected value is between ranges typical for sand and for clay. Would result in complete drainage of inactive lagoon within three years.	Freeze and Cherry (1979).
Effective porosity of aquifer medium	0.25	0.25	0.25	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	36	10	10	Appropriate for productive sand and gravel aquifer.	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	1%	"Typical" value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	10	Within range of "typical" values reported for sand. Low-risk and best estimate values equal approx. 1/10 distance to receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Transverse dispersivity (m)	7	7	1	Within range of "typical" values reported for sand. Low risk and best estimate values equal 1/3 longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 2.3.F. (cont.) Assumptions and Parameters Values for the Most Exposed Individual - Surface Impoundments: Groundwater Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Vertical dispersivity (m)	1	1	1	Within range of "typical" values reported for sand.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
TCDD K_D in aquifer	10,000	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.
Distance to model well (m)	200	200	200		

Notes: NA = Not Applicable.

$$\text{Max } C_W = \frac{C_{DW}}{K_D}$$

$$K_D = K_{OC} f_{OC}$$

where:

C_W = the concentration of contaminant in impoundment liquid (ug/ml),

C_{DW} = the dry weight concentration of contaminant in sludge (ug/g),

K_D = soil/water partition coefficient for contaminant (cm^3/g)

K_{OC} = organic carbon partition coefficient for the contaminant (cm^3/g)

f_{OC} = fraction of organic carbon in sludge (unitless)

As an alternative approach, it is reasoned that TCDD and TCDF from a typical surface impoundment may not reach the aquifer during the active lifetime of the facility. If so, then long term loadings of TCDD and TCDF may be better modeled based on the assumption that the surface impoundment has lost its excess moisture and behaves as a soil column similar to those modeled in Section 2.1.2 for landfills. The SESOIL model allows a more comprehensive approach to contaminant transport through soil layers. The model considers monthly climate data, and maintains a mass balance for contaminant transport through multiple soil layers. "Best estimates" of potential human exposure and risks through the groundwater pathway, are derived by using the SESOIL model to simulate TCDD and TCDF transport to the aquifer once steady state conditions have been reached in the unsaturated zone. SESOIL simultaneously estimates movement of TCDD and TCDF from the landfill to both groundwater and ambient air. Loadings to groundwater are proportional to assumed recharge beneath the landfill. A value of 43 centimeters recharge per year has been selected based on GEMS data for a county in Wisconsin.

Using AT123D to Predict Contaminant Transport through the Aquifer

From estimated loadings of TCDD and TCDF to groundwater, the AT123D model (Yeh, 1980) can be used to predict contaminant concentrations at wells down-gradient of each site. As with landfills, this analysis considers only the "steady state" concentrations predicted by the model, without regard to the amount of time required to reach steady state.

Methods for Estimating Human Exposure and Individual Risk

Based on assumed rates of individual water ingestion per day, exposure over an entire lifetime, and rates of absorption of TCDD and TCDF from drinking water, individual exposure and cancer risk can be calculated by:

$$E_D = W F_A C_D/B_W$$

$$I_{RD} = E_D q^*$$

where:

B_W = average body weight (assumed to be 70 kg)

C_D = estimated water concentration at distance D (mg/l)

E_D = average lifetime individual exposure (mg/kg/day)

F_A = fraction of contaminant absorbed from ingested water (unitless)

I_{RD} = lifetime individual cancer risk (lifetime^{-1})

q^* = cancer slope factor for TCDD or TCDF $(\text{mg/kg/day})^{-1}$

W = amount of water consumed daily (liters)

Exposure and risk are estimated separately for persons taking drinking water at each of the three model distances from a surface impoundment site. Maximum exposure and risk is assumed to occur at the nearest well location.

Methods for Estimating Sizes of Exposed Populations

The sizes of populations potentially exposed to drinking water contaminated by surface impoundments are estimated with the same methods discussed in Section 3.4 for landfills. For each surface impoundment site, data from FRDSPWS were combined with data from the National Well Water Association, the Statistical Abstracts, and some assumptions about site and plume sizes to derive rough estimates of the number of persons likely to take drinking water from wells down-gradient of each site. Examination of FRDSPWS data reveals that the density of persons using groundwater in counties with surface impoundments is about 50 percent lower, on average, than the corresponding average density in counties with landfills.

Data Sources and Model Inputs for Estimating the Rates of Water Seepage Beneath Surface Impoundments

U.S. EPA (1987c) examined seepage rates beneath municipal wastewater lagoons, and found that a sludge layer on the bottom of a lagoon can decrease the hydraulic conductivity of soils beneath the lagoon by one to two orders of magnitude. Based on measured seepage rates beneath lagoons built above a variety of soil media, they selected a range of 0.1 to 0.3 in/day (3×10^{-6} tc 9×10^{-6} cm/sec) as representative of seepage rates beneath municipal wastewater lagoons. The extent to which this range might also apply to impoundments receiving pulp and paper sludge is unknown.

Tables 2.3.E and 2.3.F list the assumptions and parameter values used to estimate rates of water seepage beneath an impoundment. For "high risk" exposure estimates, it is assumed that the medium underlying the impoundment is composed of silty sand, with hydraulic conductivity of 1×10^{-3} cm/sec (Freeze and Cherry, 1979) and effective porosity of 0.25 (Yeh, 1981). It is further assumed that the sludge layer on the bottom of the impoundment reduces seepage to 1×10^{-5} cm/sec, a value just beyond the upper end of the range established for municipal wastewater lagoons. By combining these assumptions with an assumed net precipitation of 43 cm per year (a value taken from the CLIMATE data base in GEMS for a relatively high rainfall area in Wisconsin), one can estimate that the impoundment will lose about 3 meters of water per year, so that an inactive impoundment of 3-9 meters depth would drain completely within 1 to 3 years.

For a "best estimate" of seepage beneath an impoundment, it is assumed that the impoundment is no longer active when TCDD and TCDF eventually reach the aquifer beneath a site. Recharge to groundwater beneath the site is estimated based on monthly weather data from a weather station in Wisconsin.

Data Sources and Model Inputs for Estimating Contaminant Concentrations in Seepage Beneath an Impoundment

The "high risk" estimate is based on the highest reported dry weight contaminant concentrations among mills in the 104-Mill Study that use surface impoundments: 3800 ng/kg for TCDD, and 17,100 ng/kg for TCDF. Best estimate calculations use concentrations of 501 and 2087 ng/kg, respectively. Parameter values listed in Tables 2.3.E and 2.3.F are used to estimate that the yearly loading of TCDD and TCDF to an aquifer beneath 150 acres of surface impoundment is unlikely to exceed about 6×10^{-10} kg/year of TCDD and 7×10^{-7} kg/hour of TCDF. At this rate the mass of contaminant in a filled impoundment would not be depleted for thousands of years.

Data Sources and Model Inputs for Estimating Contaminant Transport through the Aquifer

Assumed characteristics for the aquifer media beneath surface impoundments are listed in Tables 2.3.E and 2.3.F. To derive a "high risk" estimate of human exposure, this analysis considers a productive aquifer composed of sand and gravel with a hydraulic conductivity of 10 m/hour, porosity of 0.25, and organic carbon content of 0.1 percent. These values of porosity and conductivity are within the appropriate ranges reported in Freeze and Cherry (1979). The assumed value for organic carbon content is deliberately low, to limit the adsorption of TCDD and TCDF to the solids in the aquifer. This assumption does not affect steady state concentrations predicted by AT123D, however.

Based on these assumptions, together with others listed in Tables 2.3.E and 2.3.F, the AT123D model provides expected water concentrations in the aquifer at down-gradient distances of 200, 1,200, and 3,000 meters. This analysis considers only the "steady-state" concentrations predicted by AT123D. These concentrations may not be reached for hundreds of years after sludge is first placed in the impoundment.

2.3.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources

The extent of exposure and risks associated with surface water pathways for surface impoundments will depend on the characteristics of individual surface impoundment sites, and on management practices used to contain the sludge. If a facility is surrounded by a substantial berm, for example, runoff from the impoundment will be minimized. This analysis conservatively assumes that runoff from an inactive surface impoundment will result in the same amount of soil transport from the facility per unit area as estimated for landfills without cover. The methodology presented in this Section is thus nearly identical to the approach discussed in Section 2.1.3.

As with landfills, if sludge particles erode from a surface impoundment then TCDD and TCDF adsorbed to those particles may be introduced into lakes or streams. If humans consume water or fish from these lakes or streams, they may be exposed to TCDD and TCDF from the sludge. This Section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health. The methodology consists of three general steps. First, based on sludge concentrations of TCDD and TCDF, local topography, land use and other factors, it estimates contaminant concentrations in sediments, surface water, and fish. Second, it uses these estimated concentrations, assumptions about individual ingestion of drinking water, and assumptions about the bioavailability and the cancer slope factors for TCDD and TCDF, to estimate individual health risks for humans potentially exposed. Third, it combines these results with estimates of the size of exposed populations to derive estimates of total human health risks to the U.S. population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Details of the methods used for these calculations are presented in Appendix B. In general, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the surface impoundment. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the surface impoundment surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases, based on the assumption of equilibrium partitioning between the two phases.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Drinking Water from Surface Water Sources

Water concentrations are multiplied by human consumption of water and a bioavailability factor to yield the estimated human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$\text{Dose}_w = \frac{C_w Q_w BA_w}{BW}$$

where:

C_w = Concentration of contaminant in water (mg/liter)

BA_w = Bioavailability of TCDD or TCDF from ingested water (unitless)
BW = Human body weight (assumed to be 70 kg)

Q_w = Individual's consumption of water (liters/day)
Dose_w = Dose of contaminant from consumption of water (mg/kg/day)

Methods for Estimating the Size of Exposed Populations

The size of the population exposed to contaminated water is estimated by multiplying the area of the drainage basin above each SMA drainage point by the estimated population density of that area. This estimated population is then multiplied by the fraction of the population that takes its drinking water from surface supplies:

$$PE_w = A_B \, PD \, PSW$$

where:

PE_w = Population exposed to contaminated water
A_B = Area of the drainage basin (ha)
PD = Population density for region of surface impoundment (persons/ha)
PSW = Percent of population served by surface water

Data Sources and Model Inputs for Estimating Soil Contaminant Concentrations

In this analysis, surface impoundments are assumed to be uncovered; reliable data are not at this time available for management practices at pulp and paper sludge surface impoundments. For a surface impoundment without soil cover, initial soil concentrations are assumed to equal sludge concentrations. "Best estimate and "low risk" calculations for typical individuals use the average sludge concentration reported for all of the surface impoundments. "High risk" typical individual estimates and the MEI scenarios are based on the highest reported sludge concentrations. Sludge concentrations were taken from the "104-Mill Study" (U.S. EPA, 1989c).

Data Sources and Model Inputs for Estimating Sediment Contaminant Concentration

As explained in Appendix B, the parameters necessary to calculate sediment concentration (before partitioning) from soil concentration are: site area, site sediment delivery ratio, drainage area, drainage area sediment delivery ratio, and the Universal Soil Loss Equation parameters.

The soil concentrations are discussed above. The surface impoundment areas are assumed to be 30 hectares in the typical "low risk" and "best estimate" scenarios and 60 hectares in the typical "high risk" and the MEI scenarios. These areas are suggested by U.S. EPA (1985).

The calculation for the SMA sediment delivery ratio, as shown above, depends on the overland distance between the SMA and the water body. Based on U.S. EPA (1988a), the distance to surface water is assumed to be 152 meters in the typical "low risk" and "best estimate" scenarios and 30 meters in the typical "high risk" and MEI scenarios.

The watershed sediment delivery ratio is dependant on the area of the watershed. The "best estimate" and "high risk" typical individual estimate assume the water body receiving runoff from the impoundment site is a major stream with a watershed area of 5,000 square miles. This estimate is based on U.S. EPA Geographic Exposure Modeling System (GEMS) estimates of drainage area for major streams (U.S. EPA, 1989c). The "low risk" typical individual estimate assumes that the receiving water body is a smaller tributary with a watershed area of 500 square miles. The watershed in the MEI scenarios is assumed to be 10,000 acres (approximately 40 square miles). This area corresponds to a relatively small stream (U.S. EPA 1988a).

The cover management, "C", and support practice, "P", variables from the USLE equation are determined as a ratio of SMA to watershed. This analysis assumes that surface impoundments are surrounded by pasture land. "C" values on permanent pasture, range, and idle land range from approximately 0.3% to 45%, with an average of approximately 10% (Science and Education Administration, 1978). In other words, the approximate average soil loss from pasture under specified conditions is 10 percent of the corresponding loss from clean-tilled, continuous fallow. In the typical "low risk" and "best estimate" scenarios, the surface impoundments are assumed to be 90 percent covered with vegetation, resulting in a "C" ratio of 1.1:1. The typical "high risk" and the MEI scenarios more conservatively assume that the surface impoundments have no vegetative cover. This assumption results in a "C" ratio of 10:1. All scenarios conservatively assume that no support practices are in place since insufficient information on support practices is available. Therefore the "P" ratio in all scenarios is 1:1.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the partition coefficient between water and organic carbon, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the partition coefficient between sediment and water. The Koc value for TCDD used in this analysis is 1×10^7 (Jackson, 1985 in EPA, 1987c). The Koc value for TCDF is 3.5×10^4 (CHEMEST procedure in GEMS, U.S. EPA, 1989c). The organic carbon content of the sediment is assumed to be 0.04 in the "low risk" typical individual estimate, 0.01 in the typical individual and MEI "best estimate", and 0.001 in the "high risk" typical individual and MEI estimate (U.S. EPA, 1988a).

Data Sources and Model Inputs for Estimating Human Dose

Individual water consumption is assumed to be 2 liters per day (U.S. EPA, 1988a). The bioavailability of ingested water is assumed to be 100 percent (EPA, 1989c). Other parameter values used for estimating human dose to TCDD and TCDF from surface water are listed in Table 2.3.G. for typical individuals and Table 2.3.H for the most exposed individual.

Table 2.3.G. Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
SMA Soil Cover	None	None	None		
SMA Vegetative Cover	90%	90%	None		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
"C" ratio	1.1:1	1.1:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	
"P" ratio	1:1	1:1	1:1	Assumes no support practices	
Distance from site to surface water (meters)	152	152	30		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Drainage Area (ha)	129,500	1,295,000	1,295,000	"Best" and "high" scenarios assume the sites drain into a major waterway. The "low risk" scenario assumes the sites drain into a smaller tributary.	
Percent Organic Carbon in Soil	0.04	0.01	0.001		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2	2		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)

Table 2.3.G. (cont.) Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100	100		
Fish to sediment ratio					Low and best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
- Dioxin	.0967	.0967	10		
- Furan	.1538	.1538	10		
Fish consumption (grams/day)	6.5	6.5	16	Includes fresh water and estuarine fish and shellfish.	Low and best: U.S. EPA "Estimating Exposure 2,3,7,8 TCDD" (1988), OHEA, Exposure Assessment Group (Draft) (Draft) High: U.S. EPA "Risk Assessment for Dioxin Contamination Midland Michigan," April, 1988
Percent of fish consumed by the exposed population that is contaminated	100	100	100		
Human Absorption:					
Water:	100	100	100		
Fish:	85	90	95		U.S. EPA memo from Dioxins in Paper Work Group. "Bio-availability of Dioxins in Paper Products," 6/23/89

Table 2.3.G. (cont.) Assumptions and Parameter Values for a Typical Individual - Surface Impoundments: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5	0.5		U.S. EPA memo, "Bioconcentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	57	57	57		U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	49	49	49		U.S. Geological Survey (1985)
Sportfisher fish consumption (grams/day)	N.C.	48	48		Humphrey (1983) in U.S. EPA (1988)
Percent of population consuming fish at Sportfisher level	N.C.	3.7	3.7		US Department of Agriculture, "National Food Consumption Survey, 1977-1978"

Notes: N.C. = Not calculated.

Table 2.3.H. Assumptions and Parameter Values for the Most Exposed Individual - Surface Impoundments: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
SMA Soil Cover	None	None		
SMA Vegetative Cover	None	None		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
"C" ratio	10:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
"P" ratio	1:1	1:1	Assumes no support practices	
Distance from site to surface water (meters)	30	30		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Drainage Area (ha)	4047	4047	Assumes that the SMA drains into a relatively small stream.	U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Percent Organic Carbon In Sediment	0.01	0.001		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)

Table 2.3.H. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Surface Impoundments: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Percent of water consumed that is contaminated	100	100		
Fish to sediment ratio (whole body)				Best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA, (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
--[a]Dioxin	.0967	10		
-- Furan	.1538	10		
Fish consumption (grams/day)	100	100		Humphrey (1976) in EPA (1988), "Risk Assessment for Dioxin Contamination. Midland, Michigan."
Percent of fish consumed that is contaminated	100	100		
Human Absorption:				
Water:	100	100		
Fish:	95	95		U.S. EPA memo from Dioxins in Paper Work Group. "Bio-availability of Dioxins in Paper Products," 6/23/89
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA (1989) memo, "Bio-concentration Factors for 2,3,7,8-TCDD and TCDF," August.

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

The size of the exposed population is estimated by multiplying the watershed area of the contaminated stream by the average population density of the regions in which the surface impoundments are located. To accurately estimate population exposed on a site-specific basis, it is necessary to know the stream into which runoff from the impoundment area drains, the dilution and dispersion pattern of the contaminant, and the patterns of water withdrawal from the water body. In the absence of this site-specific information, the size of the exposed population is estimated as described below.

The typical "best estimate" scenario assumes that the receiving stream for each surface impoundment is a major stream with a 5,000 square mile watershed area. It is further assumed that the size of the exposed population increases with stream size, and that stream size increases with drainage area i.e., the larger the drainage area, the more people are likely to use the stream for a drinking water supply. To capture this relationship, the size of the exposed population is approximated by the number of persons expected to live in the area of the drainage basin containing each surface impoundment. The area of each basin (assumed to be 5,000 square miles for all surface impoundments in the "best" estimate) is multiplied by the average population density per unit area in the regions through which the waterway flows. Population density is determined by averaging populations for the regions of the United States within which a surface impoundment is located and dividing by the area for these regions. Regional populations were considered rather than state populations because the contaminated waterways are not constrained by state boundaries. The average population density for regions where surface impoundments are sited is estimated as 57 people per square mile (U.S. Department of Commerce, 1987).

Only a portion of this population will rely on surface water for their drinking water. The estimated population exposed is therefore reduced by multiplying by the national average percentage of population served by surface water, obtained from USGS (1985).

This analysis assumes that the entire exposed population ingests water at concentrations estimated at the "point" of entry of the runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles in the "best" estimate, this assumption is conservative, and will tend to overstate exposure and risk. In reality, dilution and dispersion of the contaminant will have occurred before much of the population is exposed. However, in the absence of additional site-specific information, it was not possible to calculate exposure more exactly.

One test of the reasonableness of the analysis' assumption about the size of the exposed population is to compare the amount of drinking water assumed to be withdrawn from the contaminated stream with the stream's flow rate. If the stream cannot supply the quantity of water that the analysis assumes is ingested then the assumptions must be reexamined.

The "best" risk estimate for the population assumes that a water body with a drainage area of 5000 square miles is contaminated. A water body with this drainage area would be a relatively major stream, receiving runoff from an area approximately 70 by 70 miles. Several streams located near paper mills have a drainage area of a few thousand square miles. For example, Raccoon Creek at Granville, OH has a drainage area of 8,270 square miles (U.S. EPA, 1989d).

The U.S. Geological Survey (USGS) has studied the relationship between a stream's drainage area and mean annual flow rate using regression analysis. On a national scale, USGS found drainage area to be the most significant variable influencing flow rate; other variables, particularly average annual precipitation, were also sometimes significant (personal communication, USGS). Since annual precipitation varies substantially throughout the United States, drainage area alone is not a precise predictor of stream flow. However, the general relationship between drainage area and stream flow can be estimated for regions of the country.

For regions east of the Mississippi, the range of stream flows associated with a drainage area can be approximated from the following equations (personal communication, USGS).

Low Estimate

$$MAF = DRA$$

High Estimate

$$MAF = 1.5\ DRA$$

where:

DRA = Drainage area (square miles), and
MAF = Mean annual flow rate (cubic feet per second or cfs).

Regions west of the Mississippi will exhibit greater variability in stream flows with relationship to drainage area, with extremely arid areas approaching zero cubic feet per second per square mile of drainage area. However, moderately arid regions are likely to exhibit a relationship between stream flow and drainage area that can be approximately represented by the following equation.

$$MAF = 0.5 DRA$$

Using these formulas to predict mean annual flow rates for a stream with a 5,000 square mile drainage area yields 5,000 to 7,500 cfs in relatively humid (generally eastern) states and about 2,500 cfs in relatively arid (generally western) states. Converting to liters per year, the mean flow rates are 4.5×10^{12} to 6.7×10^{12} liters/year for humid states. Arid states have a mean annual stream flow rate of approximately 2.2×10^{12} liters per year associated with a stream with a 5,000 square mile drainage area.

The flow rate for a stream with a 5,000 square mile drainage area can be compared with the quantity of drinking water assumed to be withdrawn from the stream to evaluate the feasibility of assumptions about the size of the exposed population. To estimate drinking water withdrawals, the exposed population is multiplied by the quantity of water consumed per person. The analysis assumes that a person consumes 2 liters of water per day. The population exposed varies between different types of sludge use or disposal, based on the population density of the regions of the country in which the SMA's are located. The exposed population also varies according to the percent of the population that receives its drinking water from surface water. For surface impoundments, the population exposed to contaminated water is estimated to be 28 people per square mile of drainage area.

Water will be assumed to be withdrawn from a stream with a relatively low stream flow:drainage area ratio, since some surface impoundments are located in arid states. Water withdrawal for drinking is calculated by multiplying 5,000 square miles of drainage area by 28 exposed people per square mile. This yields an exposed population of 140,000 people. Total surface water withdrawal for drinking, at 2 liters per person per day, is 1.0×10^{8} liters/year. Comparing the water withdrawals to the stream flow shows that about 0.005 percent of the stream flow is withdrawn for human consumption.

It is likely that the population receiving its drinking water from contaminated surface water will receive the remainder of water for domestic uses from this same source. Therefore, it is also informative to compare total water withdrawn for domestic use with the stream flow. Average domestic water use is 78 gallons, or 295 liters, per person per day (USGS, 1985). Multiplying 295 liters per day by a population of 140,000 yields estimated annual domestic use of 1.5×10^{10} liters per year. Total domestic use would therefore represent about 0.7 percent of total stream flow.

In evaluating the plausibility of these calculations, one should note that 77% of water used domestically is return flow (USGS, 1985). This means that the water reaches a ground- or surface-water source after release from the point of use and thus becomes available for further use. The above discussion suggests that the assumptions in this analysis about population exposed to surface water area are plausible.

2.3.4 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Where pulp and paper sludge is deposited in uncovered surface impoundments, particles of sludge or soil from the surface impoundment can be transported by erosion to nearby lakes or streams. If the sludge contains TCDD or TCDF, then the particles can carry these contaminants to the surface water bodies. Fish living in the lakes or streams can take up sludge contaminants into their tissue; if humans then consume those fish, they can be exposed to TCDD and TCDF.

This section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health. The methodology is quite similar to that discussed in Section 2.3.3, in that both methodologies begin by estimating sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from surface impoundments. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 2.3.3, and uses fish to sediment bioconcentration factors and estimates of human fish consumption to estimate contaminant doses to humans. The last step in the methodology involves estimating the sizes of exposed populations, combining these results with estimates of individual dose and health risk to derive total health risks to the entire exposed population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Methods used for these calculations are described in detail in Appendix B. In summary, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the surface impoundment. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the surface of the surface impoundment, the methodology derives estimates of the concentration of contaminants in the sediment. These sediment concentrations can then be used to estimate contaminant concentrations in the tissues of fish.

Methods for Estimating the Concentration of TCDD and TCDF in Fish Tissues, as a Function of Sediment Concentrations

Methods for estimating contaminant concentrations in fish are discussed in detail in Appendix B. Based on the assumption that sediment concentrations are the best predictor of fish concentrations of hydrophobic compounds like TCDD and TCDF, the methodology uses empirical fish to sediment bioconcentration factors to estimate concentrations of contaminant in freshwater fish as a function of concentrations in stream or lake sediment. As explained in Appendix B, the concentrations of TCDD and TCDF in the muscle tissues of fish (consumed by humans) are considered to be fifty percent lower than the fish whole body concentrations of these contaminants.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Fish

Estimated contaminant concentrations in fish tissue are multiplied by an estimated amount of fish consumed daily and a bioavailability factor to yield human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$Dose_F = \frac{C_F \, Q_F \, BA_F}{BW}$$

where:

BA_F = Bioavailability of TCDD or TCDF from fish (unitless),

BW = Human body weight (assumed to be 70 kg),

C_F = Concentration of contaminant in fish tissue (mg/g),

Q_F = Individual's daily fish consumption (g/day),

$Dose_F$ = Dose of contaminant from consumption of fish (mg/kg/day).

Methods for Estimating the Size of Populations Exposed to TCDD and TCDF through Ingestion of Fish

The population exposed to fish containing TCDD and TCDF is estimated by multiplying the area of the drainage basin of the contaminated water body by an estimated population density of the regions containing the impoundments.

$$PE_F = A_B\,PD$$

where:

PE_F = Population exposed to contaminated fish,

A_B = Area of the drainage basin (ha),

PD = Population density for region of the surface impoundment (persons/ha).

Data Sources and Model Inputs for Estimating Soil Contaminant Concentration.

In this analysis, surface impoundments are assumed to be uncovered; reliable data are not at this time available for management practices at pulp and paper sludge surface impoundments. For a surface impoundment without soil cover, initial soil concentrations are assumed to equal sludge concentrations. "Best estimate and "low risk" calculations for typical individuals use the average sludge concentration reported for all of the surface impoundments. "High risk" typical individual estimates and the MEI scenarios are based on the highest reported sludge concentrations. Sludge concentrations were taken from the "104-Mill Study" (U.S. EPA, 1989c).

Data Sources and Model Inputs for Estimating Sediment and Fish Contaminant Concentrations

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 2.3.G for typical individuals and Table 2.3.H for the most exposed individual.

Data Sources and Model Inputs for Estimating Human Dose

A contaminant dose from ingestion of contaminated fish is estimated for three populations: typical individuals, an MEI, and sport fishers. As an input to the dose calculation, consumption of freshwater and estuarine fin fish and shellfish is estimated for these three populations. Numerous studies report quantities of fish consumed by humans but most include marine fish. U.S. EPA has cited 6.5 grams/day as the average freshwater fish consumption (U.S. EPA, 1980, in U.S. EPA 1988a). The Food and Drug Administration (FDA) has estimated 16 grams per day as the upper 90th percentile ingestion rate of freshwater fish in the Great Lakes area (U.S. EPA, 1988b). This analysis assumes fish consumption of 6.5 grams per day for a typical individual in the "low risk" scenario and "best estimate" and a consumption rate of 16 grams per day for the typical individual "high risk" exposure estimate.

Since these overall averages include a large proportion of individuals who eat no freshwater fish at all, particular populations may consume larger quantities. In particular, sport fishers are likely to consume fish at a higher rate than a typical individual. The "best estimate" and "high risk" sport fisher scenarios incorporate the assumptions used in the population "best estimate" and "high risk" scenarios, respectively except they use different rates of fish consumption and a smaller exposed population to reflect the typical behavior of sport fishers. This analysis assumes sport fishers consume 48 grams of fish per day in both the "best estimate" and the "high risk" scenarios. This is the median consumption rate for sport fishers in Michigan reported by Humphrey (1983). The MEI analyses uses the 90th percentile consumption rates of active sport fishers, 100 grams per day, to represent MEI consumption rates (Humphrey, 1976).

Bioavailability rates for the contaminants consumed in fish are taken from U.S. EPA (1989c). TCDD and TCDF are assumed to be 85, 90, and 95 percent bioavailable for "low", "best", and "high" calculations, respectively. Contaminants consumed with fish are assumed to be 95 percent bioavailable in both the "best" and "high" MEI risk estimates.

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

This analysis assumes that all fish are consumed regionally. An alternative would be to assume that the fish are distributed nationally. In that case, the percent of the freshwater fish each person consumes from the contaminated stream might be calculated by calculating the ratio of the drainage area of the contaminated stream to the drainage area of the entire United States. This percentage could then be used as the percent of contaminated freshwater fish consumed by the entire U.S. population. Instead, the current methodology uses drainage area to determine the proportion of U.S. citizens who are exposed to the contaminated water and fish. This population is then assumed to consume 100% of their freshwater fish from the contaminated stream. These two methods will yield similar estimates of total risk to the population since the analysis assumes a linear dose-response relationship.

As previously discussed, sizes of exposed populations are estimated by multiplying the estimated watershed area by the estimated population density. To accurately estimate site-specific populations exposed it is necessary to know the stream into which the SMA runoff drains, the downstream uses of the surface water (e.g., fishing, drinking), and the distribution of the fish that are caught. In the absence of this site-specific information, the size of the exposed population is estimated as follows.

It is assumed that the size of the population exposed will be positively correlated with stream size and that stream size will be positively correlated with ~~drainage area; the larger~~ the drainage area, the more people are likely to receive their drinking water supply from the stream. To quantify this relationship, population exposed is modeled as a function of drainage area. Each unit area of the watershed is multiplied by the average population density for the regions through which the waterways flow to yield population exposed. For surface impoundments, the population density is estimated to be 57 people per square mile.

In the "best estimate" and the "high risk" scenarios for typical individuals, it is assumed that the receiving stream for each SMA is a major stream with a 5,000 square mile watershed area. In the "low risk" estimate for typical individuals, the drainage area is assumed to be one-tenth of this size, or 500 square miles. The drainage area in both MEI scenarios is assumed to be about 40 square miles. This corresponds to a relatively small stream (U.S. EPA, 1988a).

To calculate the sportfisher population exposed to contaminated fish, the total population exposed is first calculated as described above. The percentage of U.S. non-metropolitan households consuming "home produced" fish and poultry is estimated to be 7.1% (U.S. Department of Agriculture 1978). The percentage of these households consuming "home produced" poultry is estimated at 3.4% (U.S. Department of Agriculture 1978). If the populations home-producing poultry and fish do not overlap then 3.7% of the population home-produces fish. To estimate the population consuming fish at the median sportfisher level of 48 grams per day, the total population exposed is multiplied by 3.7%. This calculation assumes that the family of a sportfisher consumes fish at the same rate as a sportfisher.

This analysis assumes that the entire exposed population ingests fish at concentrations appropriate for the "point" of entry of the SMA runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles in the "best" and "high" estimates, this assumption is conservative, and will tend to overstate exposure and risk. In reality, dilution and dispersion of the contaminant would have occurred before much of the population was exposed.

2.3.5 Summary of Results

Table 2.3.I shows estimated human exposure from each pathway associated with surface impoundments. Exposure through consumption of fish from contaminated surface water sources shows the highest risk to the MEI, followed by ingestion of contaminated surface water. Table 2.3.J reports human health risks associated with these levels of exposure. As is clear from the table, estimated risks to the MEI through pathways associated with surface runoff are quite high. These pathways also result in the greatest population risk.

Table 2.3.1. Best Estimate of Human Exposure from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed:	9×10^{-11}	(0.8)	6×10^{-13}	(0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed:	2×10^{-12}	(0.5)	8×10^{-15}	(0.9)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed:	2×10^{-8}	(0.8)	1×10^{-12}	(0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	7×10^{-8}	(59)	2×10^{-13}	(60)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	6×10^{-8}	(59)	2×10^{-12}	(60)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$$

Table 2.3.J Best Estimate of Human Health Risk from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-5} (0.8)	2×10^{-7} (0.8)	7,100,000	2×10^{-2} (0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-7} (0.5)	2×10^{-9} (0.9)	4,074	1×10^{-7} (0.9)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-3} (0.8)	3×10^{-7} (0.8)	1,950,000	8×10^{-3} (0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-2} (59)	6×10^{-8} (60)	4,000,000	3×10^{-3} (60)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-2} (59)	4×10^{-7} (60)	147,000	9×10^{-4} (60)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^{5} / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

REFERENCES FOR SECTION 2.3

Aller, L., Bennett, T. Lehr, J.H., Petty, R.J. (1985). DRASTIC: A Standardized System for Evaluating Ground Water Pollution Potential Using Hydrogeological Settings, U.S. EPA Office of Research and Development, Ada, Oklahoma, May.

Bonazountas, M., and Wagner, J.M., (1984). "SESOIL" A Seasonal Soil Compartment Model. Arthur D. Little Inc. and DIS/ADLPIPE Inc. for the U.S. EPA Office of Toxic Substances, Contract No. 68-01-5271, May.

Bowers, J.F. et al. (1980). Industrial Source Complex (ISC) Dispersion Model User's Guide (Vol. 1). PB80-133044. U.S. EPA, Research Triangle Park, NC.

Freeman, R.A., and Shroy, J.M. (1985). Environmental mobility of TCDD, Chemosphere, Vol. 14, No. 6/7, pp 873-876.

Freeze R.A., and Cherry, J.A. (1979). Groundwater. Prentice Hall, Inc., Englewood Cliffs, NJ.

Hwang, S.T. (1982). Toxic Emissions from Land Disposal Facilities. Environmental Progress. 1:46-52. February.

Hwang and Falco (1986). Estimation of Multimedia Exposures Related to Hazardous Waste Facilities. In: Cohen, Y., ed. Pollutants in a Multimedia Environment. Plenum Publishing Co. New York, NY.

Jackson, D.R., Roulier, M.H., Grotta, H.M., Rust, S.W., Warner, J.S., Arthur, M.F., and DeRoos, F.L. (1985). Leaching potential of 2,3,7,8-TCDD in contaminated soils, in land disposal of hazardous waste. In Proceedings of the Eleventh Annual Research Symposium at Cincinnati, OH, April 9-May 1, 1985. Sponsored by the U.S. EPA Office of Research and Development, Cincinnati, OH. NTIS PB85-196376.

Lyman, W.J., Reehl, W.F., and Rosenblatt, D.H.(1982), Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds, McGraw-Hill Book Company, New York.

MacKay, D., and Yeun, A. (1983). Mass transfer coefficient correlations for volatilization of organic solutes from water. Environmental Science and Technology. 17:211-217.

Mill, T. (1985). Prediction of the Environmental Fate of Tetrachlorodioxin, in Dioxins in the Environment, M.A. Kamrin, and P.W. Rodgers eds., Hemisphere Publishing Corporation, Washington, 1985.

Neal, H.A. (1987). Solid Waste Management and the Environment: the Mounting Garbage and Trash Crisis, Prentice-Hall, Englewood Cliffs, NJ.

Podoll, R.T., Jaber, H.M., and Mill, T. (1986). Tetrachlorodibenzodioxin: rates of volatilization and photolysis in the environment. Environ. Sci. Technol. 20(5): 490-2.

Schroy, J.M., Hileman, F.D., and Cheng, S.C. (1986). Physical/Chemical Properties of 2,3,7,8-Tetrachlorodibenzo-p-dioxin. In:ASTM Spec. Publ. 891 (Aquat. toxicol. Haz. Assess. 8th Symp.): 409-21.

Springer, C., P.D. Lunney, and K.T. Valsaraj (1984). Emission of Hazardous Chemical for Surface and Near Surface Impoundments to Air. U.S. Environmental Protection Agency, Solid and Hazardous Waste Research Division. Cincinnati OH. Project Number 808161-02, pp. 3-4 to 3-16. December.

U.S. Bureau of the Census (1988), Current Industrial Reports, Washington.

U.S. EPA (1985). Summary of Data on Industrial Non-Hazardous Waste Disposal Practices. Office of Solid Waste and Emergency Response, Washington, DC. December.

U.S. EPA (1986). Development of Advisory Levels for Polychlorinated Biphenyls (PCBs) Cleanup. Office of Health and Environmental Assessment, Washington, DC. EPA 600/6-86-002. NTIS PB86-232774/AS.

U.S. EPA (1987a). The Regional Dioxin Study: Tiers 3, 5, 6, and 7. Office of Water Regulations and Standards, Washington DC. EPA 440/4-87-003.

U.S. EPA (1987b). User's Guide to SESOIL Execution in GEMS. Prepared by General Sciences Corporation, for the Office of Pesticides and Toxic Substances, Exposure Evaluation Division, Contract No. 68-02-4281, November.

U.S. EPA (1987d). Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) -- Air Emission Models. Office of Air Quality Planning and Standards, Research Triangle Park, NC., EPA-450/3-87-026, December.

U.S. EPA (1987e). Report to Congress: Municipal Wastewater Lagoon Study, Vols. I and II. Office of Municipal Pollution Control, Washington, DC. November.

U.S. EPA (1988a). Estimating Exposures to 2,3,7,8-TCDD. Office of Health and Environmental Assessment, EPA/600/6-88/005A. External Review Draft, March.

U.S. EPA (1988b). Risk Assessment for Dioxin Contamination, Midland, Michigan. EPA-905/4-88-005. April.

U.S. EPA (1989a). Training Materials for GEMS and PCGEMS, Office of Pesticides and Toxic Substances, January.

U.S. EPA (1989b). Hazardous Waste Treatment, Storage, and Disposal Facilities (TSDF) - Air Emissions Models, Office of Air Quality Planning and Standards, EPA-450/3-87-026. Draft.

U.S. EPA (1989c). 104-Mill Study data, Office of Water Regulations and Standards, July 26, 1989 version.

U.S. EPA (1989d). Graphical Exposure Modeling System User Guide. Office of Toxic Substances. March.

U.S. Geographical Survey (1970). A Proposed Stream Flow Data Program for Alabama. Available for each state. Open File Reports.

Yeh, G.T. (1981). AT123D: Analytical Transport One-, Two-, and Three-Dimensional Simulation of Waste Transport in the Aquifer System. Oak Ridge National Laboratory, Environmental Sciences Division, Publication No. 1439. March.

2.4 Exposure and Risks from Land Application of Pulp and Paper Sludge

Land application of sludge, while an alternative disposal method, also fertilizes and conditions soil and makes use of the sludge as fill. According to the 104-Mill Study and follow-up conversations with state environmental offices, sludge from four mills in three states is used on forests, sludge from two mills in two states is applied to agricultural land, and sludge from two mills in two states is used to reclaim abandoned mine sites. Conversations with state environmental offices indicate that approximately 325,000 dry metric tons of sludge are being land applied per year with about 10% to mine reclamation, 10% to agriculture, and 80% to forests. This section examines the risks to human health from the land application of pulp and paper mill sludges.

Land application practices are estimated for each group of sites in a state. The type of application, application rate, years land receives sludge, acres receiving sludge, depth of incorporation, sludge concentrations, and soil concentrations averaged over 70 years are displayed for each state in Table 2.4.A for the typical analysis, and in Table 2.4.B for the MEI analysis. Human risk estimates use the average soil contamination over the human lifespan (assumed to be 70 years).

Since likely exposure pathways differ depending on the type of land receiving the sludge, exposure pathways considered in this analysis differ for agricultural, mine, and forest application. In addition, farmers will be exposed to TCDD and TCDF from agricultural application through pathways that are not relevant to the population at large. The following pathways of exposure are considered in this analysis:

Human risk estimates for forest application and mine reclamation consider two pathways for both a total population and an MEI risk:

- Contaminated soil erodes from the forest or mine site and contaminates surface water and stream sediment. The surface water serves as a drinking supply.

- Contaminated soil erodes from the forest or mine site and contaminates surface water and sediment. TCDD and TCDF is incorporated into fish tissue and fish are consumed by humans.

Human risk estimates from agricultural application consider the two pathways above and add the following pathway:

Table 2.4.A. Parameters and Model Inputs Used for a Typical Exposure Assessment to Model Land Application Practices

State	Type of application	Application rate (DMT/Ha)	Years land receives sludge	Incorporation Depth (cm)	Sludge concentration TCDD	Sludge concentration TCDF	Soil TCDD conc (ppt) 70 yrs.	Soil TCDF conc (ppt) 70 yrs.
Georgia	forest	2,065	1	2.5	220	610	181	501
Maine	forest	40	1	2.5	13	55	1	5
Maryland	mine	224	1	0	80	471	80	471
Mississippi	agriculture	58	70	15	681	0	330	0
Ohio	mine	224	1	0	145	795	145	795
Pennsylvania	agriculture	18	20	15	34	10	4	1
Wisconsin	forest	40	1	2.5	109	1300	9	106

Table 2.4.A. (cont.) Parameters and Model Inputs for a Typical Exposure Assessment Used to Model Land Application Practices

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	57	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	2.12×10^{-6}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 2.4.A. (cont.) Parameters and Model Inputs Used for a Typical Exposure Assessment to Model Land Application Practices

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	57	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306	306		
TCDF Koc	3.5×10^4	3.5×10^4	3.5×10^4		Both values from ChemEst procedure in Gems. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

Table 2.4.A. (cont.) Parameters and Model Inputs Used for a Typical Exposure Assessment to Model Land Application Practices

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Areas receiving sludge (ha/year)					Estimates from state environmental officials
Georgia	81	81	81		
Maine	405	607	810		
Maryland	26	26	40		
Mississippi	405	405	405		
Ohio	81	81	81		
Pennsylvania	30	30	30		
Wisconsin	1,012	1,012	1,012		

Table 2.4.B. Parameters and Model Inputs Used for a MEI Exposure Assessment to Model Land Application Practices

State	Type of application	Application rate (DMT/Ha)	Years land receives sludge	Incor-poration Depth (cm)	Sludge concen-tration TCDD	Sludge concen-tration TCDF	Soil TCDD conc (ppt) 70 yrs.	Soil TCDF conc (ppt) 70 yrs.
Georgia	forest	2,065	1	2.5	220	610	181	501
Maine	forest	40	1	2.5	13	55	1	5
Maryland	mine	224	1	0	80	471	80	471
Mississippi	agriculture	58	70	15	681	0	330	0
Ohio	mine	224	1	0	145	795	145	795
Pennsylvania	agriculture	18	20	15	34	10	4	1
Wisconsin	forest	40	1	2.5	109	1300	9	106

Table 2.4.B. (cont.) Parameters and Model Inputs for a MEI Exposure Assessment Used to Model Land Application Practices

Input parameter	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 2.4.B. (cont.) Parameters and Model Inputs Used for a MEI Exposure Assessment to Model Land Application Practices

Input parameter	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306		
TCDF Koc	3.5×10^4	3.5×10^4		Both values from ChemEst procedure in Gems. Low value from Karickhoff method; best and high estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

Table 2.4.B. (cont.) Parameters and Model Inputs Used for a MEI Exposure Assessment to Model Land Application Practices

Input parameter	Best estimate	High	Notes/explanation	Reference
Areas receiving sludge (ha/year)				Estimates from state environmental officials
Georgia	81	81		
Maine	810	810		
Maryland	40	40		
Mississippi	405	405		
Ohio	81	81		
Pennsylvania	30	30		
Wisconsin	1,012	1,012		

- Small amounts of contaminant are taken up into the tissues of crops. These crops are then either consumed or fed to animals which bioconcentrate the contaminant and produce a meat or dairy product that is consumed.

Exposure pathways particular to farmers living on a land application site are:

- Children and adults in the farming household come into direct dermal contact with the sludge-amended soil in both outdoor and indoor settings. TCDD and TCDF from the sludge is absorbed through the skin. Children ingest small amounts of the sludge/soil mixture through normal mouthing behavior. Adults also inadvertently ingest small quantities of sludge/soil.

- TCDD and TCDF applied to the farmland volatilizes from the sludge into the air. Residents of the farm inhale the volatilized TCDD and TCDF.

- Particles of the sludge/soil mixture become suspended in the air during application. Residents of the farm inhale the contaminated particles.

The following sections describe the methods and data used to estimate risks from land application of sludge through these pathways. Results are summarized in the final section. To assist the reader, an example calculation of typical risk resulting from consumption of produce grown from sludge-amended land in Mississippi is included in Appendix D.

2.4.1 Estimates of Exposure and Risks from Dermal Contact with Skin

Humans coming in direct contact with sludge contaminated soils may absorb TCDD and TCDF through their skin. The amount of TCDD and TCDF absorbed will depend on the area of skin exposed and on the length of time that the contaminated soil is in contact with the skin. The following discussion summarizes the model used to estimate exposure through dermal contact.

To estimate exposure through direct contact with soil containing TCDD and TCDF, methodologies presented in Schaum (1984), Hawley (1985), and EPA (1988a) were used. The model uses empirically-derived information on the amount of soil or dust that adheres to a square centimeter of skin, the area of skin exposed in various settings and the absorption rate of TCDD or TCDF through skin to derive the dose of TCDD or TCDF from dermal contact with contaminated soil or dust.

Description of Calculations

The calculation of dermal exposure proceeds in two steps. First the average daily exposure from dermal contact is calculated as the product of area of skin affected, the contact rate, the dermal absorption rate and the duration of contact. Second, the risk from dermal contact is calculated using the estimate of daily exposure and the cancer slope factors of TCDD and TCDF.

Description of Exposure Calculations

The concentration of TCDD and TCDF in the soil outdoors is derived as described in Appendix A. The concentration of TCDD and TCDF in indoor dust is calculated as follows:

$$C_{in} = C_{out}\ F$$

where:

C_{in} = concentration of TCDD or TCDF in dust indoors, mg/mg
C_o = concentration of TCDD or TCDF in soil outdoors, mg/mg
F = ratio of indoor dust concentrations to outdoor soil concentrations

The indoor dust and outdoor soil contaminant concentrations are used to estimate human exposure and risk from dermal contact with these media. Daily doses are estimated for three age groups: young children (ages 1-6), older children (ages 7-11) and adults (ages 12 and older). The dose for each age group is calculated as:

$$DOSE_g = [(C_o\ CR_{o,g}\ SA_{o,g}\ H_{o,g}\ AB_d\ M) + (C_{in}\ CR_{in,g}\ SA_{in,g}\ H_{i,g}\ AB_d\ M)]/\ BW_g$$

where:

AB_d = systemic absorption rate through the skin
BW_g = body weight = 70 kg for adult, 16 kg for young child, 35 kg for older child
C_o = concentration of TCDD or TCDF in soil outdoors, mg/mg
C_{in} = concentration of TCDD or TCDF in dust indoors, mg/mg
$CR_{in,g}$ = contact rate of soil with skin for age group g, indoors, mg/cm^2
$CR_{o,g}$ = contact rate of soil with skin for age group g, outdoors, mg/cm^2
$DOSE_g$ = dose from outdoor exposure for age group g, mg/kg/day
$H_{i,g}$ = hours spent indoors for age group g
$H_{o,g}$ = hours spent outdoors for age group g
$SA_{in,g}$ = surface area of skin exposed to soil for age group g, indoors, cm^2
$SA_{out,g}$ = surface area of skin exposed to soil for age group g, outdoors, cm^2
M = matrix effect on absorption rate, percent

For each age group, the soil contaminant concentration (expressed in mg/mg for ease of calculation) is multiplied by the soil contact rate outdoors (mg/cm^2) and by the area of the skin exposed during outdoor activity (cm^2) to obtain the total quantity of soil-bound TCDD or TCDF adhering to the skin (mg). The quantity of contaminant on the skin is then adjusted by two factors: the fraction of the contaminant that migrates from the soil matrix and comes into contact with the skin (M); and the fraction of TCDD or TCDF that absorbs through the skin (AB_d). Since the dermal absorption rate is expressed as the fraction of TCDD or TCDF that is absorbed through the skin per hour of contact, it must be multiplied by the hours that the soil is assumed to be in contact with the skin. The same calculations are also performed for exposures in indoor settings, using the corresponding indoor values for the model input parameters. The total daily dermal absorption of TCDD or TCDF is the sum of indoor absorption and outdoor absorption. Dividing the total dermal absorption for each age group by the body weight for that age yields a daily dose of TCDD or TCDF through dermal absorption in mg/kg/day.

To obtain the weighted average dose over the lifetime of an individual, the following calculation is used:

$$DOSE_{avg} = \Sigma\, FRAC_g\, (DOSE_g)$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
$DOSE_g$ = daily dose for individual in age group g
$FRAC_g$ = fraction of lifetime spent in age group g

Description of Population Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with the cancer slope factors of TCDD and TCDF to obtain an estimate of lifetime risk from dermal exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg}\ q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC \ POP / LS$$

where:

LS = average lifespan of an individual = 70 years
PC = population risk, cancer cases per year
POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs

In the assessment of typical exposure, "low risk," "best," and "high risk" estimates are calculated to provide an understanding of the uncertainty in the exposure assessment. The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.4.C. In the MEI analysis, "best" and "high risk" estimates are derived. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.4.D. The best MEI exposure estimate is derived by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for Soil Concentrations

The method for deriving soil concentrations is described in Appendix A. Soil concentrations for each land application site are presented in Table 2.4.A.

Data Sources and Model Inputs for Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

Roberts et al. (1977), as discussed by Hawley (1985), studied the relationship between lead concentrations indoors and outdoors near a lead smelter, and found that the mean concentration of

Table 2.4.C. Assumptions and Parameter Values for a Typical Individual - Land Application: **Dermal Pathway**

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	0.13	0.5	1.5	Roels (1980) used in Schaum (1984) to develop high value; Lepow (1975) cited by Schaum for best estimate value; low value from Roels 1980, cited in Hawley, 1985.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	0.13	0.5	1.5	Roels (1980) used in Schaum (1980) high value; Lepow (1975) cited by Schaum for best estimate value; low value from Roels (1980) cited in Hawley, 1985.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	0.13	3.5	3.5	Best estimate: value from Hawley (1985) based on adults doing yard work Low: based on low value for children given by Hawley (1985) based on Roels (1980).	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.011	0.056	0.06	Low and high values are from Solomon and Hartord (1976) as cited by Hawley. Best estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.011	0.056	0.06	Low and high values are from Solomon and Hartord (1976) as cited by Hawley. Best estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space, indoor, adult attic	0.011	0.056 1.8 (110 mg/hr)	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985

Table 2.4.C. (con't.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Ratio of contaminant concentration indoors to soil concentration outdoors	0.75	0.80	0.85		Hawley, 1985
Time spent outdoors, child (hr)	1565	1565	2190	Low and best estimate: assumes 5 days/wk, 6 months/yr, 12 hrs/day (12 hrs before soil is washed off) High: 7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	1824	1824	2190	Low and best: child outdoors from May to September every day (150 days), 12 hrs of soil contact before washing High estimate: child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	348	1565	1565	Low assumes 8 hrs of soil contact before washing, 2 days/wk for 5 months Best and high estimate: assumes 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Low and best: Hawley, 1985 High: Adopted from Keenan, 1989
Time spent indoors, child (hr)	4380	4380	6570	Low and best: 12 hrs/day of indoor dust contact all year High: assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989
Time spent indoors, older child (hr)	1460	1460	4380	Low and best: assumes 4 hrs/day of indoor dust contact all year High: assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985

Table 2.4.C. (con't.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Time spent indoors, adult (hr) living space, attic	4380 16	4380 48	6570 72	Living space: low and best estimate assumes indoor dust contact 12 hrs/day, all year; high assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months. Attic: low assumes 1 day in attic with soil left on skin for 12 hrs while in attic plus 4 hrs before washing. Best estimate assumes 12 days with soil on skin 4 hrs/day. High assumes 12 days with soil on skin 6 hrs/day.	Adopted from Hawley, 1985
Area of skin exposed outdoor, child (cm^2)	300 cm^2	2100 cm^2	2800 cm^2	Low assumes only hands exposed (child wearing pants and long-sleeved shirt). Best estimate assumes both hands, legs and feet exposed during play. High assumes both hands, arms, legs and feet exposed.	Hawley, 1985
Area of skin exposed outdoor, older child (cm^2)	400 cm^2	1600 cm^2	3200 cm^2	Low assumes only hands exposed. Best estimate assumes both hands, forearms, legs from knees down exposed during play. High assumes both hands, legs and feet exposed during play.	Low and best estimate: Hawley, 1985 High: assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	910 cm^2	1700 cm^2	2940 cm^2	Low assumes adult is wearing long-sleeved shirt, gloves, pants, shoes. Best assumes both hands, most of forearms exposed. High assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Low: Schaum, 1984 (citing Sendroy, 1954) Best estimate: Hawley, 1985 High: Schaum, 1984 (citing Sendroy, 1954)

Table 2.4.C. (con't.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Area of skin exposed indoor, child (cm^2)	300 cm^2	500 cm^2	1000 cm^2	Low assumes only both hands exposed. Best estimate assumes area exposed equals one half of surface area of childs feet, hands and forearms. High assumes all of area of feet, hands and forearms.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	400 cm^2	400 cm^2	825 cm^2	Low and best estimate assume only hands are exposed. High assumes only forearms and hands exposed.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	900 cm^2 (living space) 1700 cm^2 (attic)	900 cm^2 (living space) 1700 cm^2 (attic)	1700 cm^2 in both attic and living space	Low and best estimate assumes hands exposed in living space, while adult wears short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat, to work in attic. High assumes adult exposed to indoor dust while wearing short-sleeved shirt with an open neck, pants, shoes, no gloves or hat.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1}	0.012 h^{-1}	0.024 h^{-1} (children only)	Low and best: Bioavailability Workgroup. High: Hawley (1985) assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.
Availability of dioxin from soil matrix	0.3%	1%	15%	Recommended value: 1%	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

Table 2.4.D. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dermal Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	1.5	1.5	Roels (1980) used in Schaum (1984) to develop high value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	1.5	1.5	Roels (1980) used in Schaum (1980) high value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	3.5	3.5	Value from Hawley (1985) based on adults doing yard work.	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.06	0.06	From Solomon and Hartord (1976) as cited by Hawley.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.06	0.06	From Solomon and Hartord (1976) as cited by Hawley.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space.	0.06	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985
indoor, adult attic	1.8 (110 mg/hr)			
Ratio of contaminant concentration indoors to soil concentration outdoors	0.80	0.85		Hawley, 1985

Table 2.4.D. (con't.) Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dermal Pathway

Input parameter	Best Estimate	High	Notes/explanation	Reference
Time spent outdoors, child (hr)	2190	2190	Assumes 7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	2190	2190	Child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	1565	1565	Assumes 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Low and best: Hawley, 1985 High: Adopted from Keenan, 1989
Time spent indoors, child (hr)	6570	6570	Assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989
Time spent indoors, older child (hr)	4380	4380	Assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985
Time spent indoors, adult (hr) living space, attic	 6570 72	 6570 72	Living space: Assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months. Attic: Assumes 12 days with soil on skin 6 hrs/day.	Adopted from Hawley, 1985
Area of skin exposed outdoor, child (cm^2)	2800 cm^2	2800 cm^2	Assumes both hands, arms, legs and feet exposed.	Hawley, 1985

Table 2.4.D. (con't.) Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dermal Pathway

Input parameter	Best Estimate	High	Notes/explanation	Reference
Area of skin exposed outdoor, older child (cm^2)	3200 cm^2	3200 cm^2	Assumes both hands, legs and feet exposed during play.	Assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	2940 cm^2	2940 cm^2	Assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Schaum, 1984 (citing Sendroy, 1954)
Area of skin exposed indoor, child (cm^2)	2800 cm^2	2800 cm^2	Assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	3200 cm^2	3200 cm^2	Assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	2940 cm^2 (attic) 2940 cm^2 (living space)	2940 cm^2 (attic) 2940 cm^2 (living space)	Assumes area exposed indoors same as outdoors.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1} 0.024 h^{-1} (children)	0.024 n^{-1} (children only)	Best: Bioavailability Workgroup. High: Hawley (1985) assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989; Hawley (1985)

Table 2.4.D. (con't.) Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dermal Pathway

Input parameter	Best Estimate	High	Notes/explanation	Reference
Availability of dioxin from soil matrix	15%	15%	Used highest value from range given in memorandum.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

the lead in household dust was 75% the concentration of lead in the outdoor soil. For his own analysis, Hawley (1985) assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The analysis of typical exposure uses a value of 80% for the best estimate, and applies a range of 75% to 85% for the low and high estimates, respectively. For the MEI analysis, the best estimate assumes a value of 80%, and the high estimate uses a value of 85%.

Data Sources and Model Inputs for Contact Rate

The contact rate of soil on skin varies between outdoor and indoor exposures and among age groups. Hawley (1985) and Schaum (1984) both described a number of studies that estimated the contact rate of soil on the skin of children playing outdoors. Lepow et al. (1975), as cited in Hawley (1985), estimated a contact rate of 11 mg soil per 21 cm^2 of skin on the hands of young children, or 0.5 mg/cm^2. Exposed skin on other parts of the body is assumed to have the same contact rate. Roels et al. (1980), as cited in Hawley (1985), found that the mean values for quantity of dirt on one hand of eleven-year old children ranged from 40 to 180 mg. Since the hand of a child this age has a surface area of approximately 300 cm^2, these data suggest a contact rate ranging from 0.13 to 0.6 mg/cm^2. Schaum (1984) reported the upper end of the estimate for outdoor contact rate for children to be 1.5 mg/cm^2. In the analysis of typical exposure, 0.5 mg/cm^2 is used for the best estimate, 0.13 mg/cm^2 the low estimate, and 1.5 mg/cm^2 the high estimate of contact rate for children. The MEI analysis uses an outdoor soil contact rate of 1.5 mg/cm^2 for older and younger children.

For adults, the outdoor contact rate was derived by Hawley (1985), based on assumed thickness of the layer of soil on the skin and the density of outdoor soil. Hawley's calculations yielded a value of 3.5 mg/cm^2. This value is used in the analysis of typical exposure for "best" and "high risk" estimates. This value is also used in the MEI analysis. For a "low risk" typical exposure estimate, outdoor contact rate for adults is assumed to be the same as the low estimate of outdoor contact rate for children.

Hawley (1985) estimated indoor contact rates based on assumptions regarding dustfall and frequency of cleaning. Hawley also cited the work of Solomon and Hartford (1976), who studied lead and cadmium levels in indoor dust. The dust values measured by these researchers ranged from 110 mg/m^2 to 590 mg/m^2. For his analysis, Hawley (1985) used a value of 0.056 mg/cm^2 for indoor dust contact rate, assuming a dustfall rate indoors that is 20% of the outdoor dustfall, and assuming biweekly cleaning of surfaces. The typical exposure analysis uses Hawley's value as a best estimate, and uses the range of values reported by Solomon and Hartford (1976, through Hawley, 1985) as low and high estimates. These values are used to represent contact rate indoors in living space for all three age groups. A value of 0.06 mg/cm^2 is used in the MEI analysis.

Adults may also experience dermal contact with soil when engaged in infrequent cleaning of seldom-used spaces, such as attics. After a discussion of the relevant literature, Hawley (1985) concluded that an adult working for a one-hour exposure in a dusty space such as an attic has indirect dermal contact with 110 mg of dust suspended in air. In addition, the direct contact rate with dust was estimated to be 1.8 mg/cm^2, based an assumed depth of the dust layer on the skin and the density of indoor dust particles. To assess risks from these exposures, the analysis of Hawley (1985) is incorporated into the typical and MEI analyses.

Data Sources and Model Inputs for Area of Skin Exposed

The surface area of skin available for contact with contaminated soil will influence the quantity of TCDD and TCDF absorbed through this pathway. The surface area available for contact will vary depending on the clothing worn by the individual. Hawley (1985) provides a table of surface area for various parts of the body for young children, older children, and adults. In the following discussion, the area of the skin assumed to be exposed in each scenario for each age group is derived from this table. The assumptions regarding the body parts exposed in each scenario are also derived from Hawley (1985), except as noted.

For the best estimate of typical exposure, it is assumed that the feet, legs and hands of young children are exposed to soil during outdoor play, an area of 2100 cm^2; indoors, one-half of the area of the hands, forearms and feet, or 500 cm^2 is assumed to be exposed. The "low risk" estimate of typical exposure assumes that only the child's hands are exposed both indoors and outdoors (300 cm^2): the rest of the body is covered with clothing. The "high risk" typical exposure estimate assumes that young children's hands, arms, legs, and feet (2800 cm^2) are exposed outdoors, while feet, hands, and forearms are in contact with indoor dust (1000 cm^2). To calculate MEI exposure estimates, a value of 2800 cm^2 is used for both indoor and outdoor exposures.

For older children, the typical exposure analysis uses a value of 1600 cm^2 for the "best" estimate of the surface area of skin exposed while playing outdoors. This value represents exposure of both hands, forearms, and half of the legs (i.e., from the knees down). Indoors, older children have 400 cm^2 of skin in contact with indoor dust, an area equivalent to the area of both hands. For the "low risk" estimate of typical exposure, the analysis assumes that only hands are exposed both outdoors and indoors. The "high risk" estimate of typical outdoor exposure is based on Keenan et al. (1989), who assumed that children playing outdoors expose both hands, legs and feet to soil. The surface area corresponding to these parts of the body for older children is approximately 3200 cm^2 (Hawley, 1985). The "high risk" estimate of typical exposure assumes that the hands and the forearms of the older child, or approximately 825 cm^2 of skin, are exposed indoors. The MEI analysis uses the value 3200 cm^2 for both indoor and outdoor exposure.

The hands and forearms of adults working outdoors are assumed to come into contact with contaminated outdoor soil. The area of these body parts is approximately 1700 cm^2. This value is used in the calculation of the "best" estimate of typical exposure. As a "low risk" estimate, Schaum (1984), citing Sendroy (1954), assumed that adults may wear a long-sleeved shirt, gloves, pants, and shoes to work outdoors. In this case, the area exposed is 910 cm^2. The "high risk" estimate of typical exposure uses a value from Schaum (1984), citing Sendroy (1954), who assumes that adults may wear a short-sleeved shirt with an open neck, pants, shoes, with no gloves or hat, to work outdoors. The area of skin exposed under these assumptions is 2940 cm^2.

For adults indoors, different assumptions can be made for the area of skin exposed while the adult is in the living space and the area exposed while the adult works in an attic. For the "low risk" and "best" estimates of typical exposure, adults working in the attic are assumed to wear an open-neck, short-sleeved shirt, pants, shoes, and no gloves or hat, while adults in the living space wear clothing that covers a larger area of skin and behave in such a manner that only the hands are in direct contact with indoor dust. This corresponds to an area of 1700 cm^2 in the attic, and 900 cm^2 in the living space. The "high risk" estimate of typical exposure assumes that 1700 cm^2 of skin are exposed in both the attic and in the living space. For calculating MEI exposures, the analysis assumes that 2940 cm^2 of skin are exposed both indoors and outdoors.

Data Sources and Model Inputs for Exposure Duration: Indoor and Outdoor Soils

The length of time soil is in contact with the skin is an important factor in determining the amount of TCDD or TCDF that is absorbed into the system through the skin. The following assumptions regarding duration of dermal exposure are derived from Hawley (1985). The "low risk" and "best" typical exposure analyses assume that young children spend 5 days a week, six months out of the year playing outdoors. The outdoor soil is assumed to remain in contact with the skin for twelve hours before it is washed off. Twelve hours are also spent in contact with indoor dust. During the winter months, young children are in contact only with indoor dust, for 12 hours per day. In the "high risk" typical exposure estimate, young children play outdoors seven days per week, six months out of the year, with soil remaining on the skin for twelve hours. The remaining twelve hours is spent in contact with indoor dust. The high estimate for young children also assumes that young children are in contact with indoor dust 24 hours a day during the six winter months. This assumption is also used in the MEI analysis.

For the typical exposure analysis, the "low risk" and "best" exposure assessments assume that older children spend some time outdoors everyday between May and September (5 months), and allow the outdoor soil collected on the skin to remain there for twelve hours before washing. In addition, older children are assumed to be in contact with indoor dust for four hours per day all year; the rest of the time is spent at school or other locations. As a "high risk" estimate, and for the MEI analysis, older children are assumed to spend some time outdoors every day for six months, and to allow the outdoor soil to remain on the skin for 12 hours before washing; furthermore, these children are in dermal contact with indoor dust for 12 hours every day year round.

Adults who live at agricultural land application sites are assumed to have dermal exposure to contaminated outdoor soil 5 days a week, six months out of the year in the "best" typical exposure calculations. Furthermore, the soil remains on the skin for twelve hours before it is washed off the skin. Indoors, adults are in contact with indoor dust for twelve hours a day all year. The "low risk" typical exposure analysis assumes that the adult lives on the farm but works elsewhere; as a result the dermal contact is reduced to only two days per week for five months of the year, the soil is assumed to remain on the skin for eight hours before washing. For the "high risk" typical analysis, and in the MEI analysis, the adult experiences dermal exposure to indoor dust for 12 hours a day during the summer months, and 24 hours a day during the winter months.

As discussed earlier in this section, adults may also have limited dermal exposure while cleaning seldom-used spaces such as attics. Hawley (1985) assumes that an adult spends 12 hours in these environments during one year. This value could represent a single cleaning, where the adult spends one twelve-hour period in the attic, or it could represent twelve one-hour cleaning sessions. For the best estimate, it is assumed that the adult spends twelve days in the attic, one hour each day, and leaves the dust from attic on the skin for four hours before washing. The low estimate assumes the adult spends one day in the attic for twelve hours, and leaves the dust on the skin for an additional four hours before washing. For the "high risk" typical estimate, and for the MEI estimate, the adult engages in twelve one-hour attic cleaning sessions, and leaves the attic dust on the skin for six hours after each session.

Data Sources and Model Inputs for Dermal Absorption of TCDD and TCDF

Dermal absorption of TCDD and TCDF bound to soil involves two components: migration of the TCDD and TCDF from the soil matrix, and absorption of TCDD and TCDF through the skin. The Consumer Product Safety Commission (1989) reviewed data pertaining to the dermal absorption of TCDD from a variety of matrices. The Consumer Product Safety Commission (CPSC) memorandum cites studies by Poiger and Schlatter (1980), who reported absorption of TCDD from wet soil ranging from 0.05% to 2.2%, and by Shu et al. (1988), who reported absorption of 0.65% to 1% with dry soil. Comparing these absorption rates to the rate of dermal absorption when TCDD is applied to the skin in a methanol vehicle, CPSC concluded that from 0.3% to 15% of the TCDD in soil is released for subsequent absorption through the skin. In the typical exposure analysis, the recommendation of the CPSC memorandum is followed and a value of 1% is used to represent the best estimate for this matrix effect for contaminated soil; the typical analysis uses the range of 0.3% to 15% for the "low risk" and "low risk" estimates, respectively. For the MEI analysis, a value of 15% is used.

CPSC also reviewed the literature regarding the percutaneous absorption of the TCDD release from the soil matrix. Studies reviewed included studies with laboratory animals and in-vitro studies of human skin. The animal studies report percutaneous absorption rates ranging from 40 to 48% over 72 hours. From the in-vitro skin experiments (Weber et al., as cited in CPSC memorandum), CPSC estimated an absorption rate of 18.5% over 17 hours of exposure, yielding a transfer coefficient of 0.012 h^{-1}. This value is used for the "low risk" and "best" typical exposure assessments for all age groups. For children, Hawley (1985) states that the absorption rate through skin for children is twice the absorption rate for adults. Therefore, in this analysis, a transfer coefficient of 0.024 hr^{-1} is used for the "high risk" typical exposure analysis and for the MEI analysis for both younger and older children.

Data Sources and Model Inputs for Estimating the Population Exposed

In this analysis, the population exposed to TCDD through dermal contact is limited to the population residing on the agricultural land application sites. The number of sites applying kraft mill sludge to land is equal to the total number of acres applied with sludge in the state divided by the average number of acres per site. Values for both the total acres and the acres per site were obtained through conversations with state officials in Mississippi and Pennsylvania, the states where agricultural land application is currently practiced. In Mississippi, 1000 acres are applied with the sludge from one mill, with an estimated 100 acres per site, yielding an estimate of 10 sites in Mississippi. Pennsylvania has 75 acres covered with sludge from one mill, with an average of 15 acres per site, giving a total of 5 sites. The total number of sites in each state is multiplied by the number of people living on each site to obtain the exposed population. According to the 1980 U.S. Census, the average number of persons per household is 2.7. In Pennsylvania, the exposed population is approximately 14 persons, while in Mississippi, the exposed population is approximately 27. The total exposed population is about 40 persons.

2.4.2 Estimates of Exposure and Risks Estimates from Ingestion of Produce, Meat, and Dairy Products Grown on Sludge-Amended Land

Sludge is applied to various types of land, including forest, abandoned mines, pasture, and land used for the production of animal feed or human food crops. This section evaluates the application of sludge to pasture and cropland, and examines the following potential pathways of exposure:

- Sludge is incorporated into the soil of farmland used for producing food crops. Contaminants in the sludge are drawn from the soil to the tissue of those crops, and are then ingested by humans who consume the crops directly.

- Sludge is incorporated into the soil of farmland used for producing animal feed or pasture. Contaminants in the sludge are absorbed into the tissues of these feeds or pasture grasses, which are then consumed by livestock. The meat and dairy products produced by these livestock are consumed by humans.

- Sludge is applied to the surface of pasture land, and adheres to the pasture grasses. Grazing cattle or sheep ingest the sludge directly as a fraction of their pasture consumption. Humans then consume contaminated beef or dairy products.

According to conversations with state environmental officials, sludge from two bleached kraft mills, one in Mississippi and one in Pennsylvania, is currently applied to agricultural land. Several hundred hectares of agricultural land are receiving the sludge at dozens of individual sites. Though it was not possible to determine the land area and crops grown at individual sites, Mississippi and Pennsylvania environmental officials indicated the overall uses of the sludges in each state. In Mississippi, four crops are receiving the sludge: corn, soybeans, wheat, and pasture. In Pennsylvania, the sludge is generally used on feed corn.

The methodology and data inputs for assessing human exposure due to sludge application to agricultural land are discussed below. The calculations for determining risk from the dietary pathway follow.

Methods for Estimating the Human Exposure to TCDD and TCDF through the Dietary Pathway

To estimate the concentration of contaminants in food products from land application of paper and pulp mill sludge, a model was created which uses information regarding sludge application rates and sludge contaminant concentrations to calculate the uptake of contaminants by crops and by animals feeding on crops and pasture. A "best estimate" of human exposure is calculated using data on human dietary consumption of these meats and crops and the quantity of contaminated produce. A "high risk" and a "low risk" scenario are evaluated. For each scenario, the model is given input data for: sludge incorporation depth, the number of years sludge is applied, the contaminated land area, sludge application rates, concentrations of individual contaminants in the sludge, uptake rates of soil contaminants to various crop tissues, uptake rates of contaminants in animal feed to meat or dairy products, the fraction of each type of feed in animal diets, the production yield of animal product per unit of food, human dietary data, the acreage of sludge-amended land devoted to each crop, the productivity of land for each crop, and the population to which the contaminated food is distributed. The model returns exposure estimates which are then used to estimate risk.

Exposure and risk are calculated for both a typical individual and a most exposed individual (MEI). The most exposed individual is assumed to be a farmer growing and applying sludge to all crop types grown on sludge-amended land in the state in which he or she resides.

Each exposure calculation consists of three steps. First, the model calculates tissue concentrations of contaminants in each crop as a result of the land application of sludge. Second, the model estimates concentrations of the contaminants in meat or dairy products. As discussed above, contaminants are assumed to enter meat and dairy products as a result of animal ingestion of sludge-treated crops and pasture grasses and of direct ingestion of sludge adhering to pasture grasses. Third, the model sums the amount of each contaminant in all crops and animal products ingested by humans to estimate typical population exposure or MEI exposure.

Method for Estimating Tissue Concentrations of Contaminants in Crops Grown on Sludge-amended Soil

Soil concentration calculations are discussed in Appendix A. The calculations for determining crop tissue contaminant concentrations from soil concentrations are:

$$CD_{ij} = C_j U_{ij} \qquad (2.4.1)$$

$$CW_{ij} = CD_{ij} \; KDW_i \qquad (2.4.2)$$

where:

CD_{ij} = Tissue concentration of pollutant j in crop i (mg/kg dry weight)

C_j = Concentration of pollutant j in the soil (mg/kg)

U_{ij} = Rate of uptake of contaminant j into tissue of crop i (mg/kg dry weight per mg/kg dry weight)

CW_{ij} = Tissue concentration of pollutant j in crop i (mg/kg fresh weight)

KDW_i = Constant for converting dry weight concentration to fresh weight concentration for crop i.

Each crop's uptake rate is applied to the soil contaminant concentrations to estimate the concentration of each contaminant per unit dry weight of crop tissue (2.4.1). Dry weight tissue concentrations are converted to fresh weight concentrations to match units of human consumption data (2.4.2).

Method for Determining Tissue Concentrations of Contaminant in Meat and Dairy Products Produced with Sludge-amended Soil

To calculate meat and dairy product contaminant concentrations, the model derives average concentration of each contaminant in each animal's feed mix. Average concentrations are calculated by taking a weighted average of the contaminant concentrations in each animal's food sources. An additional source of contaminant, direct soil ingestion, is added to the dose derived from food (2.4.3). The feed contaminant concentrations are multiplied by animal bioconcentration factors to determine fresh weight concentrations of contaminants in each meat or dairy product (2.4.4).

$$CF_{jk} = \Sigma_i(F_{ik}\ CD_{ij}) + (FD_k\ N_j) \qquad (2.4.3)$$

$$CW_{jk} = CF_{jk}\ U_{jk} \qquad (2.4.4)$$

where

CF_{jk} = Weighted average concentration of contaminant j across all food sources for animal producing meat or dairy product k (mg/kg dry weight)

F_{ik} = Fraction of animal k's food from crop i (unitless)

CD_{ij} = Concentration of contaminant j in crop i (mg/kg)

FD_k = Fraction of animal k's food from sludge (adherence pathway) (unitless)

N_j = concentration of contaminant j in sludge (mg/kg)

CW_{jk} = Tissue concentration (fresh wt) of pollutant j in meat or dairy product (mg/kg fresh weight)

U_{jk} = Rate of uptake of contaminant j into meat or dairy product k per unit of concentration in animal's food (mg/kg fresh weight per mg/kg dry weight)

Method for Determining Most Exposed Individual Dose from Contaminant Ingestion through Foods Grown in Sludge-amended Soil

Methods of calculating MEI exposure and population exposure differ. The calculation for MEI exposure proceeds in three steps. First, exposure through direct consumption of crops is calculated. To obtain the exposure from direct crop consumption, the daily dietary consumption of each crop is multiplied by the fraction of that crop produced in sludge amended soil, by the fresh weight contaminant concentration of the crop, and by the bioavailability of the pollutant when consumed with the crop:

$$D_c = \Sigma_i (CW_{ij} \ FC_i \ DC_i \ B_i \ 10^{-6})$$

where:

B_i = Bioavailability of pollutant when consumed in crop i (unitless),

CW_{ij} = Tissue concentration of pollutant j in crop i (mg/kg fresh weight),

D_c = Dose of pollutant j from crops produced with sludge-amended soil (mg/kg/day),

DC_i = Daily dietary consumption of crop i (mg/kg/day fresh weight),

FC_i = Fraction of dietary consumption of crop i grown in sludge-amended soil (unitless)

In the second step, MEI dose of the contaminant through consumption of animals raised on contaminated feed is determined. This step incorporates the contamination of animal products through both consumption of contaminated feed and through grazing. The equations are similar to those discussed for dose from crop consumption:

$$D_a = \Sigma_k (CW_{jk} \ FC_k \ DC_k \ B_k \ 10^{-6})$$

where:

B_k = Bioavailability of pollutant when consumed in meat or dairy product k (unitless),

CW_{jk} = Tissue concentration of pollutant j in meat or dairy product k (mg/kg fresh weight),

D_a = Exposure to pollutant j from animals produced with sludge-amended soil (mg/kg/day),

DC_k = Daily dietary consumption of meat or dairy product k (mg/kg/day fresh weight),

FC_k = Fraction of dietary consumption of animal product k produced from sludge-amended soil (unitless).

Finally, dose from crop and animal consumption are summed:

$D_j = D_c + D_a$

where:

D_j = Total exposure to pollutant j from crops, meat and dairy products produced with sludge-amended soil (mg/kg/day).

Method for Determining MEI Cancer Risk

Once the daily dose estimate to the MEI is estimated, it is combined with information about the cancer slope factors of TCDD and TCDF to obtain an estimate of lifetime risk from dietary exposure to these contaminants. The calculation of MEI risk is:

$IC = DOSE_{MEI}\ q_1^*$

where:

$DOSE_{MEI}$ = weighted average daily dose for an MEI, mg/kg/day

IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF

q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Method for Determining Population Contaminant Dose from Ingestion of Foods Grown in Sludge-amended Soil

Contaminant doses are calculated for each state in which sludge is applied agriculturally and then summed over these states to yield total population dose. The dose from the dietary pathway is calculated by summing three inputs: dose of contaminant bioavailable in crops for direct human consumption, dose of contaminant bioavailable in animal products contaminated by crop consumption, and dose of contaminant bioavailable in animal products contaminated by grazing. The following calculation describes typical population dose:

$TD_j = (D_j + A_j + G_j)/BW/DP/DY$

where:

Aj = Dose of pollutant j bioavailable in animal products contaminated by crop consumption (mgs/year)

DP = Population over which the crops and animal products are distributed

BW = Body weight (kgs)

DY = Days per year

D_j = Dose of pollutant j bioavailable in crops for direct human consumption (mgs/year)

G_j = Dose of pollutant j bioavailable in animal products contaminated by grazing (includes soil adherence and grass uptake) (mgs/year)

TD_j = Total exposure to pollutant j from crops, meat and dairy products produced with sludge-amended soil (mg/kg/day)

The following discussion describes the methods used to obtain each of the three components of the estimation of total dose.

Method for Determining Population Contaminant Dose from Ingestion of Crops

The dose of contaminant bioavailable in crops for direct human consumption is calculated by multiplying the mass of each crop grown on sludge-amended land that is directly consumed by humans by the tissue concentration of the crop. The result is multiplied by a bioavailability factor:

$$D_j = (MH_i \; CW_{ij} \; B_i)$$

where:

B_i = Bioavailability of pollutant when consumed in crop i (unitless),

CW_{ij} = Tissue concentration of pollutant j in crop i (mg/kg fresh weight),

MH_i = Mass of crop i grown on sludge-amended land that is consumed directly by humans (kgs fresh weight/year).

The mass of each crop grown on sludge-amended land that is consumed directly by humans is calculated by multiplying total acres of the crop receiving sludge by the crop yield. This mass is then multiplied by the percent of the crop consumed directly by humans:

$$M_i = A_i \; Y_i$$
$$MH_i = M_i \; PH_i$$

where:

A_i = Sludge-amended land area on which crop i is grown (hectares/year),

M_i = Mass of crop i grown on sludge-amended land (kgs/year),

Y_i = Yield per area of crop i (kgs/hectare),

PH_i = Percent of crop i consumed directly by humans (unitless).

Method for Determining Population Contaminant Dose from Ingestion of Animals Fed on Contaminated Crops

To determine the dose of contaminant available through consumption of animal products fed contaminated crops, the mass of each contaminated crop fed to animals is multiplied by an animal product yield from each weight unit of contaminated feed. To obtain a dose to humans who ingest the animal products, this yield is multiplied by contaminant concentration in the animal tissue, percent of the animal that is fat, and a bioavailability factor:

$$A_j = \Sigma_{ik}(MA_{ik}\ YA_k\ CW_{jk}\ B_k\ PF_k\ /\ FA_{ki})$$

where:

B_k = Bioavailability of pollutant when consumed in meat or dairy product k (unitless),

CW_{jk} = Tissue concentration of pollutant j in meat or dairy product k (mg/kg fresh weight),

FA_{ki} = Fraction of dietary consumption of crop i for animal k (unitless),

MA_{ik} = Mass of crop i grown on sludge-amended land that is fed to animal k (kgs/year),

PF_k = Percent fat in animal product k (unitless),

YA_k = Yield of animal k per unit of corn-equivalent feed (kg/kg).

To obtain the mass of each crop fed to each animal the mass of each crop fed to all animals is divided between the animals according to each animal's percentage of total consumption:

$$MA_i = M_i - MH_i$$

$$MA_{ik} = MA_i\ ((N_k\ C_k)/\Sigma_k(N_k\ C_k))$$

where:

C_k = Food consumed per animal k (kgs/year)

MA_i = Mass of crop i grown on sludge-amended land that is fed to animals (kgs fresh weight/year)

N_k = Number of animal k in the state

Method for Determining Population Contaminant Dose from Ingestion of Animals Grazing on Contaminated Pasture Land

To obtain the dose of contaminant from animal products raised on sludge-amended pasture land, the number of contaminated animals marketed is multiplied by an average production weight to yield a total mass of meat available for consumption. This mass is then multiplied by the tissue contaminant concentration, the percent of the animal that is fat, and a bioavailability factor:

$$G_j = \Sigma_g(NS_g\ WH_g\ CW_{jk}\ B_k\ PF_k)$$

where

NS_g = Number of each animal, g, grown on sludge-amended land and marketed (animals/year),

WH_g = Average U.S. production of grazing animal g per head marketed (kgs/animal).

The number of each type of animal raised on sludge-amended land is the product of the percentage of pasture land that receives contaminated sludge and the total number of animals grazed on pasture land. The resulting number of animals is then multiplied by percent of grazed animals that are marketed each year:

$$NS_g = (SP_c/P_c)\ N_g\ PM_g$$

where:

N_g = Number of grazing animal g in the counties with sludge-amended pasture,

P_c = Total pasture land in all counties with sludge-amended pasture land in state (hectares),

PM_g = Percent of grazing animals g marketed per year on a national basis,

SP_c = Sludge-amended pasture land in all counties in state applying sludge agriculturally (hectares).

Method for Determining Cancer Risk

Once the daily dose estimate is obtained, it is combined with the cancer slope factors of TCDD and TCDF to obtain an estimate of lifetime risk from dietary exposure to these contaminants. The calculation of typical individual risk is:

$$IC = DOSE_{avg}\ q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for an typical exposed individual is converted to annual total population risk (in cases per year) by multiplying individual exposure by the number of persons exposed to the individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC\ POP / LS$$

where:

LS = average lifespan of an individual = 70 years
PC = population risk, cancer cases per year
POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs

The values used for each model input are summarized in Table 2.4.F and Table 2.4.G for typical individuals and the most exposed individual, respectively. The following sections describe each input and document the data sources used to obtain values for each model input parameter.

Data Sources and Model Inputs for Soil Concentration

The methodology for calculating soil concentration is discussed in Appendix A. Estimates of application rates and depth of soil incorporation were obtained from the Bureau of Pollution Control, Mississippi Department of Environmental Quality for Mississippi sites and from the Pennsylvania Bureau of Waste Management for the Pennsylvania sites. Sludge is assumed to be soil incorporated in both states at 6 inches. Application rates are estimated at 58 dry metric tons per hectare for Mississippi and 18 dry metric tons per hectare for Pennsylvania. Table 2.4.A displays the average soil concentrations over a 70 year period assumed to result from land application of sludge.

Data Sources and Model Inputs for Sludge-amended Acreage, Crops Grown on Sludge-amended Land, and Percent of Crops Fed to Animals

The Mississippi Department of Environmental Quality estimates that approximately 1000 acres of farm land are sludge-amended in that state. The Pennsylvania Bureau of Waste Management

Table 2.4.F. Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of cow's consumption that is soil (dry weight)	1.5%	8%	10%		Low: NCASI 6/87 High: EPA "Technical Support Document for Land Application and Distribution and Marketing of Sewage Sludge," 1988
Animal product yields:					
lb beef/lb feed	0.07	0.07	0.07		U.S. Dept. of Agriculture. Agricultural Statistics, 1987
lb milk/lb feed	0.97	0.97	0.97		
lb hog/lb feed	0.17	0.17	0.17		
lb chicken/lb feed	0.40	0.40	0.40		
lb catfish/lb feed	0.5	0.5	0.5		
Percent of product that is fat:					
beef	8	10	13		Kimbrough et al., 1984 Wisconsin Human Exposure Assessment, 1989 NCASI, 6/87
milk	4	4	4		
hog	6	7	8		
chicken	10	10	10		
Fish filet concentration as a percent of whole body concentration	50	50	50		EPA - "Bioconcentration Factors for TCDD and TCDF", August, 1989

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Uptake rates - (dry weight)					Low: Wipf, et al., 1982 High: Young, 1983 Best: EPA memo, Dioxins in Paper Work Group, 6/23/89
wheat	0.001	0.02	0.15		
corn	0.001	0.02	0.15		
grass	0.001	0.02	0.15		
soybeans	0.001	0.02	0.15		
Fish fillet BCF	0.05	0.05	5	Fish whole body BCF's have been multiplied by .5 to adjust from whole fish concentration to fillet concentration as suggested by U.S. EPA. The fish:sediment ratio from the EPA bioconcentration memo is used for the "low" and "best" estimate. The highest fish:sediment ratio reviewed in US EPA 1988 is used in the "high" risk estimate.	Low and best: EPA memo: "Bioconcentration Factors for TCDD and TCDF", 8/89 High: EPA "Estimating Exposures to 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group, (Draft)
Beef fat BCF (fresh weight)	3	4	6		Fries, 1982
Milk fat BCF (fresh weight)	3	4	5		Fries, 1982
Hog fat BCF (fresh weight)	3	4	6	Assumed to be equal to beef fat	
Chicken fat BCF (fresh weight)	3	4	6	Assumed to be equal to beef fat	

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Animal consumption (% of total dry wt consumption)					US EPA "Human Health Risk Assessment for Municipal Sludge Disposal," 1989; Delta Western Feed Mill for catfish data
- corn					
beef	2	2	2		
dairy	8	8	8		
hogs	77	77	77		
chicken	59	59	59		
- soybeans					
catfish	50	50	50		
- pasture					
beef	38	38	38		
dairy	38	38	38		
Human bioavailability via ingestion					EPA memo from "Dioxins in Paper Work Group" 6/23/89: "Bioavailability of Dioxins in Paper Products"
wheat	0.60	0.65	0.70		
corn	0.60	0.65	0.70		
beef	0.85	0.90	0.95		
dairy	0.85	0.90	0.95		
hogs	0.85	0.90	0.95		
chicken	0.85	0.90	0.95		
soybeans	0.60	0.65	0.70		
fish	0.85	0.90	0.95		
Size of population over which produce is distributed					
- MS produce	239,000,000	239,000,000	239,000,000		MS Cattle Industry Board; U.S. Statistical Abstracts, 1987
- PA produce	40,000,000	40,000,000	40,000,000		Harrisburg, PA Department of Agriculture; U.S. Statistical Abstracts, 1987

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
% dry matter					FDA "Reanalysis of FDA Revised Total Diet Food List" in EPA, "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge, 1986.
grains	0.26	0.26	0.26		
soybeans	0.08	0.08	0.08		
grass	0.05	0.05	0.05		

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway, Mississippi

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Total sludge area (ha)	405	405	405		State contact: Bureau of Pollution Control, Mississippi Dept. of Environmental Quality
% of area producing:					State contacts: Bureau of Pollution Control, Mississippi Dept. of Environmental Quality; County Extension Agent for Perry County, MS
wheat	23%	23%	23%		
corn	28%	28%	28%		
soybeans	39%	39%	39%		
pasture	10%	10%	10%		
% wheat to animals	0	0	0		County Extension Agent for Perry County, MS
% corn to animals	90%	90%	90%		
% soybeans to animals	40%	40%	40%		
% of animal corn fed to:					
beef cows	96%	96%	96%	State contact said there are no commercial dairy cows though farmers may have them for own use. From agricultural statistics, multiplied beefs, hogs, and chickens in the state by the amount they each consumed. Summed to get total consumption and then took %'s consumed by beefs, hogs, chickens.	County Extension Agent for Perry County, MS and Agricultural Statistics, 1987
hogs	3%	3%	3%		
chickens	1%	1%	1%		
dairy cows	0%	0%	0%		
% of animal soybeans fed to catfish	100	100	100	The county extension agent reports that approximately 50% of soybeans fed to animals serve as catfish feed. The remainder are fed to hogs, broilers and laying hens. In the absence of information on quantities fed to each animal and on the animal yield per unit soybean feed, all soybeans fed to animals are assumed to be fed to catfish	Perry County Extension Agent

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway, Mississippi

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Amount of beef produced from sludge amended pasture (kgs)	5084	5084	5084	Divided Perry and Forest Counties sludge-amended pasture by total pasture in the counties. Applied this percentage to marketed cows for the 2 counties. Multiplied by kilograms per cow.	County Extension Agent, Perry County; Bureau of Pollution Control MS Dept. of Environmental Quality; Agricultural Statistics, 1987
Crop yields (bushels/ha):					
wheat	94	94	94		U.S. Department of Agriculture "Agricultural Statistics" 1985
corn	173	173	173		
soybean	60	60	60		

Table 2.4.F. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Dietary Pathway, Pennsylvania

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Total sludge area (ha)	30	30	30		State contact: Bureau of Waste Management Wilkesbury Regional Office
% of area producing corn	100	100	100		State contact: Bureau of Waste Management Wilkesbury Regional Office
% corn to animals	100	100	100		State contact: Bureau of Waste Management Wilkesbury Regional Office
% corn to dairy cows	100	100	100		Harrisburg Dept. of Agriculture
Corn yield (grain) (bushels/ha)	272	272	272		U.S. Department of Agriculture, "Agricultural Statistics" 1985

Table 2.4.G. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dietary Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Percent of cow's consumption that is soil (dry weight)	8%	10%		Low: NCASI 6/87 High: EPA "Technical Support Document for Land Application and Distribution and Marketing of Sewage Sludge," 1988
Percent of product that is fat:				
beef	13	13		Kimbrough et al., 1984 Wisconsin Human Exposure Assessment, 1989 NCASI, 6/87
milk	4	4		
hog	8	8		
chicken	10	10		
Fish fillet concentration as a percent of whole body concentration	50	50		EPA - "Bioconcentration Factors for TCDD and TCDF", August, 1989
Animal consumption (% of total dry wt consumption)				US EPA "Human health Risk Assessment for Municipal Sludge Disposal," 1989; Delta Western Feed Mill for catfish data
- corn				
beef	2	2		
dairy	8	8		
hogs	77	77		
chicken	59	59		
- soybeans				
catfish	50	50		
- pasture				
beef	38	38		
dairy	38	38		

Table 2.4.G. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dietary Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Human bioavailability via ingestion				EPA memo from "Dioxins in Paper Work Group" 6/23/89: "Bioavailability of Dioxins in Paper Products"
wheat	0.70	0.70		
corn	0.70	0.70		
beef	0.95	0.95		
dairy	0.95	0.95		
hogs	0.95	0.95		
chicken	0.95	0.95		
soybeans	0.70	0.70		
fish	0.95	0.95		
Uptake rates - (dry weight)				High: Young, 1983 Best: EPA memo, Dioxins in Paper Work Group, 6/23/89
wheat	0.02	0.15		
corn	0.02	0.15		
grass	0.02	0.15		
soybeans	0.02	0.15		
Fish fillet BCF	0.05	5	Fish whole body BCF's have been multiplied by .5 to adjust from whole fish concentration to fillet concentration as suggested by U.S. EPA. The fish:sediment ratio from the EPA bioconcentration memo is used for the "low" and "best" estimate. The highest fish:sediment ratio reviewed in US EPA 1988 is used in the "high" risk estimate.	Best: EPA memo: "Bioconcentration Factors for TCDD and TCDF", 8/89 High: EPA "Estimating Exposures to 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group, (Draft)
Beef fat BCF (fresh weight)	4	6		Fries, 1982
Milk fat BCF (fresh weight)	4	5		Fries, 1982

Table 2.4.G. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dietary Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Hog fat				
BCF (fresh weight)	4	6	Assumed to be equal to beef fat	
Chicken fat				
BCF (fresh weight)	4	6	Assumed to be equal to beef fat	
% dry matter				
grains	0.26	0.26		FDA "Reanalysis of FDA Revised Total Diet Food List" in EPA, "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge, 1986.
soybeans	0.08	0.08		
grass	0.05	0.05		
% home grown				
grains	2	2		EPA: "Development of Risk Assessment Methodology for Land Application and Distribuvion and Marketing of Municipal Sludge," 1986
legumes	17	17		
milk	40	40		
meat	44	44		
poultry, fish	34	34		
Consumption (mg/kg/day)				EPA Office of Pesticide Programs' Tolerance Assessment System dietary data base
wheat	1,031	1,031		
corn	693	693		
beef fat	191	191		
dairy fat	1,424	1,424		
hog fat	146	146		
chicken	508	508		
soybean oil	1,359	1,359		
fish	59	59		

Table 2.4.G. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dietary Pathway, Pennsylvania

Input parameter	Best estimate	High	Notes/explanation	Reference
Total sludge area (ha)	40	40		State contact: Bureau of Waste Management Wilkesbury Regional Office
% of area producing corn	100	100		State contact: Bureau of Waste Management Wilkesbury Regional Office
% corn to animals	100	100		State contact: Bureau of Waste Management Wilkesbury Regional Office
% corn to dairy cows	100	100		Harrisburg Dept. of Agriculture

Table 2.4.G. Assumptions and Parameter Values for a Most Exposed Individual - Land Application: Dietary Pathway, Mississippi

Input parameter	Best estimate	High	Notes/explanation	Reference
Total sludge area (ha)	405	405		State contact: Bureau of Pollution Control, Mississippi Dept. of Environmental Quality
% of area producing:				State contacts: Bureau of Pollution Control, Mississippi Dept. of Environmental Quality; County Extension Agent for Perry County, MS
wheat	23%	23%		
corn	28%	28%		
soybeans	39%	39%		
pasture	10%	10%		
% wheat to animals	0	0		County Extension Agent for Perry County, MS
% corn to animals	90%	90%		
% soybeans to animals	40%	40%		
% of animal corn fed to:				
beef cows	96%	96%	State contact said there are no commercial dairy cows though farmers may have them for own use. From agricultural statistics, multiplied beefs, hogs, and chickens in the state by the amount they each consumed. Summed to get total consumption and then took %'s consumed by beefs, hogs, chickens.	County Extension Agent for Perry County, MS and Agricultural Statistics, 1987
hogs	3%	3%		
chickens	1%	1%		
dairy cows	0%	0%		
% of animal soybeans fed to catfish	100	100	The county extension agent reports that approximately 50% of soybeans fed to animals serve as catfish feed. The remainder are fed to hogs, broilers and laying hens. In the absence of information on quantities fed to each animal and on the animal yield per unit soybean feed, all soybeans fed to animals are assumed to be fed to catfish	Perry County Extension Agent

estimates that about 50 acres of agricultural land in that state are amended with sludge. The Mississippi Department of Environmental Quality stated that the major crops grown on sludge-amended land are wheat, corn, and soybeans and that a small amount of sludge is applied to grazing pasture. This analysis assumes that 90% of the Mississippi sludge-amended land is split between wheat, corn, and soybeans and that 10% is pasture land. The wheat, corn, and soybean percentages of land are proportioned according to the land use of the two Mississippi counties which receive the sludge. This data was obtained from the county extension agent from one of the counties. In this analysis 23% of the sludge-amended land in Mississippi is assumed to produce wheat, 28% to produce corn, and 39% to produce soybeans. Estimates of the percentages of these crops that are consumed directly by humans were also obtained from the county extension agent. One hundred percent of the wheat, 10% of the corn, and 60% of the soybeans are assumed to be consumed directly by humans. The Pennsylvania Bureau of Waste Management stated that the major crop grown on sludge-amended land was corn. One hundred percent of this corn is assumed to be animal feed.

Data Sources and Model Inputs for Animals Consuming Sludge-amended Corn and Soybeans and Percentage of Crop to Each Animal

Specific animals consuming sludge-amended corn and soybeans in Mississippi were determined through discussions with a Mississippi county extension agent. This analysis assumes that Mississippi animal corn is fed to beef cattle, hogs, and chickens (broilers). The percentage of contaminated corn fed to each of these animals was estimated as the product of the number of each type of animal in Mississippi and the average consumption of each animal divided by the sum of these products for all animals consuming contaminated feed. These data are displayed in Table 2.4.E. The resulting assumptions are that 96% of the corn fed to animals is fed to beef cattle, 3% to hogs, and 1% to broilers.

Though soybeans grown in the two Mississippi counties that apply contaminated sludge may be fed to hogs, chickens (broilers), and laying hens, the majority of the soybeans fed to animals are fed to catfish (Mississippi county extension agent). Since additional information on the percentages fed to catfish and to other animals is unavailable, 100% of the contaminated soybeans fed to animals are assumed to be fed to catfish. This assumption will affect exposure results to the degree that bioconcentration factors (BCF), the contaminated percentage of the animal, and animal product yield per unit feed differ between catfish and the other animals that may consume contaminated soybeans. Bioconcentration factors, (discussed below) for hogs and broilers are higher than the bioconcentration factor for catfish in "best estimates". No uptake rate assumption for eggs has been made but fat content of eggs is assumed to be the same as the fat content of chicken (Pocchiari, et al, 1986). Because bioconcentration factors used in the "best estimate" are higher for hogs and chickens than

Table 2.4.E. Distribution of Animal Feed

	Number of Animals In MS (thousands)	Food Consumed/Head (lbs)	Number of Animals X Food Consumed (thousands of lbs)	Percent of Total Consumption
Hogs	285	1,200	342,000	3
Chicken	5,000	28	140,000	1
Beef Cattle	1,588	5,994	9,518,472	96
Total	6,873	7,222	10,000,472	100

*USDA (1985) "Agricultural Statistics."

for catfish, the assumption that 100% of soybeans are fed to catfish may understate risk. However, catfish yield per unit of food (discussed below) is higher than the yields for the other animals. Furthermore, the BCF for catfish reflects the contaminant concentration in the filet whereas the BCF for hogs and chickens estimates the concentration in the animals' fat. The fat percentage of the animal is a small percentage of the total animal product consumed. Therefore, the assumption that all contaminated soybeans fed to animals are fed to catfish probably results in risk estimates approximately equal to the risk estimates from a scenario where some soybeans are fed to other animals.

Data Sources and Model Inputs for Crop Yields

In order to determine the quantity of contaminated food available for consumption, this analysis calculates the crop yield specific to each state for the planted acres (U.S. Department of Agriculture, 1985). These numbers are reported in Table 2.4.F.

Data Sources and Model Inputs for Animal Feed Mixes

The level of animal tissue contamination depends on the percent of the animals' diet that is contaminated. Commodity Maps from the U.S. Department of Agriculture (US Department of Agriculture, 1982) provide information on these feed mixes. From these data, and from pasture data described below, the percentage that each type of crop contributes to an animal's total diet can be derived.

Estimates for pasture consumption were derived from AGDATC data base maintained by the Oak Ridge National Laboratory. Dividing an estimated national total of 202.7 million metric tons of pasture consumption per year among beef cattle, milk cattle and lambs, estimates for the pasture fraction of beef cattle and milk cattle were obtained. Table 2.4.H summarizes national feed totals for beef and milk cattle, chickens, and hogs. Catfish data are not included in the AGDATC data base. Instead, a Mississippi catfish feed mill was consulted to obtain the fraction of a catfish diet that consists of soybeans. According to this source, soybean meal constitutes approximately one half of the diet of farmed catfish (Delta Western Feed Mills, 1989).

Grazing animals - beef cattle and milk cattle in this analysis - also directly ingest some sludge due to sludge adherence to pasture grasses. U.S. EPA (1988b) describes various studies that have attempted to quantify the amount of sludge that grazing animals ingest. Studies have found that approximately eight percent of forage consisted of sludge ~~7-21 days after~~ sludge application. EPA selected this value to approximate the sludge fraction of grazing animals' diets when setting national criteria for municipal sewage sludge regulations. This value was used in the current analysis for the

Table 2.4.H. Animal Feed Mixes

	Beef (mmt)	Milk (mmt)	Chicken (mmt)	Hogs (mmt)
Corn	6.30	19.70	9.50	43.9
Grain	--	--	--	--
Hay	73.10	34.00	--	--
Other Feed	2.70	3.60	0.80	2.20
Other Feed Grain	1.40	3.00	0.40	2.90
Other High Protein	0.10	1.00	0.80	1.20
Other Harvested Roughages	64.20	70.00	--	--
Pasture (estimated)	102.51	99.34	--	--
Protein Supplement	--	--	--	--
Sheep Pellets	--	--	--	--
Soybeans	2.75	19.00	4.45	6.99
Wheat	0.10	0.30	0.20	0.04
TOTAL	253.16	249.94	16.15	57.23

NOTES:

From the Oak Ridge Agdatc database national production of pasture is estimated to be approximately 202.7 million metric tons per year. This is divided among milk production, beef, and lamb in proportion to total tonnage of other feeds consumed by these animals (50.5% to Beef, 48.9% to Milk, 0.57% to Lamb).

"best estimate" of typical and MEI risk. Ranges of soil ingestion estimates used in this analysis are from 1.5% in the "low" risk estimate (NCASI, 1987) to 10% in the "high" risk estimate (U.S. EPA, 1988b). In all cases, the percentages of other foods in the grazing animal's diet are reduced to accommodate estimated dietary percentage from sludge ingestion.

Data Sources and Model Inputs for Animal Yields per Unit of Food Consumed

The estimate of the quantity of contaminated food that is available for human consumption uses a relationship between animal food intake and animal product produced. Data from the U.S. Department of Agriculture (1985) provides feed consumption per unit of production in equivalent feeding value of corn for milk cows, beef cattle, broilers, and hogs. These data are used to obtain animal product yield for Mississippi and Pennsylvania animals consuming corn. In the absence of more specific knowledge and information on animal yields from consumption of corn silage, this analysis assumes that in Pennsylvania and Mississippi the corn fed to animals is grain. The animal yield data are listed in Table 2.4.F.

Since the corn-equivalent feeding value of grass was not known, the production units of grazing animals were calculated separately. Sludge is only applied to pasture in Mississippi. Of the 1000 acres receiving sludge in Mississippi, 10 percent, or 100 acres, are assumed to be pasture land (Mississippi agricultural extension agent). The two counties in Mississippi applying sludge agriculturally have a total pasture land of 43,000 acres according to conversations with a Mississippi agricultural extension agent. Therefore approximately 0.2% of the pasture land is estimated to be sludge-amended. The two counties have approximately 24,000 beef cows and cattle. Assuming the cattle are grazed equally over all the pasture land, 48 cattle would be grazed on sludge-amended land. Data from USDA (1985) indicates that of the national beef cow and cattle holdings for 1985, 54% were marketed in 1985. Applying this percentage to Mississippi beef cows and cattle grazed on sludge-amended land, the estimate of the number marketed per year is 26. Finally, USDA data indicate that the average beef cattle produces 433 pounds per head which, when multiplied by the 26 marketed cows and cattle, results in 11,258 marketed pounds (5100 kgs) of cows and cattle grazed on sludge-amended pasture.

To obtain catfish yield per unit of feed, a Mississippi catfish feed mill was consulted. According to this source, one unit of feed yields approximately one-half unit of catfish production (Delta Western Feed Mill, 1989).

Data Sources and Model Inputs for Uptake Rates to Plant Tissue

U.S. EPA has reviewed studies of plant uptake and has estimated above ground plant uptake at 2 percent (U.S. EPA, 1988a). This estimate is based largely on the data presented in Sacchi et al. (1986) and Wipf et al (1982). A more recent EPA memo evaluated new studies to determine the need for modification to this uptake rate and concluded that there was no support for modification. A 2% uptake rate (dry weight) is used for the aboveground crops for typical and MEI "best estimates" in this evaluation.

Uptake rates, however, are uncertain. Studies have variously found no TCDD in edible aboveground portions (fruits and grains) of plants in contaminated soil (Wipf, 1982) (soil level approximately 10,000 ppt; detection limit 1 ppt); and uptake rates of 15 percent (Young, 1983). In addition, TCDD and TCDF volatilization and subsequent adsorption onto plant cuticles may be occurring but not captured in some experiments. In this analysis, an uptake rate of 0.001 is used for typical individual "low risk" and 0.15 for typical individual and MEI "high risk".

Data Sources and Model Inputs for Animal Bioconcentration Factors

From crop uptake rates and from information on the typical diets of livestock, the average dry weight concentrations of contaminants in animal feeds can be calculated. The rates at which animals incorporate these feed contaminants into their tissues are then used to calculate concentrations of the contaminants in meats or dairy products. Bioconcentration factors for animals are listed in Table 2.4.F for typical individuals and 2.4.G for the MEI. The uptake rates for TCDD and TCDF are assumed to be equal to each other for all animals except fish.

Beef and milk fat uptake rates for halogenated hydrocarbons are reviewed by Fries (1982). Fries assumes that the disposition of ingested residues is the same regardless of the dietary component that contains the residue. He evaluates information on the relationship of dietary residue to the resulting product residue and applies this relationship to all routes of dietary exposure.

Fries reports that a given intake level of contaminant will product similar steady-state residue levels in the milk fat of dairy cows and the body fat of non-lactating animals. He suggests an uptake rate of 4-5 times the dietary concentration (plant dry weight concentration to animal fresh weight concentration) at all dietary concentrations for milk fat at steady state (reached within 60 days). Several long-term studies involving cattle and sheep fed halogenated hydrocarbons indicate a steady-state uptake rate of 5-6 times the concentration in the diet (plant dry weight concentration to animal fresh weight concentration) with those compounds that produced the highest tissue concentration relative to diet concentration. Cattle study durations were 712 and 476 days, with steers found to reach a steady-state concentration in about 280 days (Bovard et al, 1971 and Rumsey and Bond, 1974). Hog fat and chicken fat bioconcentration factors are assumed to be equal to beef fat. This analysis assumes a bioconcentration factor of 4 in the typical and MEI "best estimates" for all animals except catfish.

"Low" and "best" bioconcentration factors for fish based on dietary intake are taken from U.S. EPA (1989h). The mean fish BCF for TCDD from contaminated dietary sources was given as 0.0967 (whole body, wet weight basis) in the EPA memo. This BCF was based on seven measurements. U.S. EPA referenced one study of bioconcentration of TCDF from dietary sources. This study measured bioconcentration for a warm water species as 0.1538 on a whole body, wet weight basis.

Since contaminated sediment can result in fish being exposed to a contaminant through the dietary pathway, fish to sediment ratios also estimate bioconcentration from dietary sources. U.S. EPA (1988a) reviewed a variety of studies of fish to sediment ratios and observed that the ratios typically range from 1:1 to 10:1. A dietary bioconcentration factor of 10 is used in this analysis for the typical individual and MEI "high" risk estimates for both TCDD and TCDF. To estimate fish filet concentrations from whole fish concentration, bioconcentration factors are multiplied by 0.5 (U.S. EPA, 1989h).

Data Sources and Model Inputs for MEI Dietary Consumption

Since the methodology for calculating typical population exposure computes the quantity of contaminated food available for consumption and then distributes this food over the consuming population, it is not necessary to estimate the percent of dietary consumption which is contaminated with sludge. The MEI analysis, on the other hand, estimates exposure as a percent of MEI consumption and requires dietary information.

For the MEI the estimates of dietary consumption are drawn from the U.S. EPA's Office of Pesticide Programs' Tolerance Assessment System (TAS) dietary data base (U.S. EPA, 1987a). The TAS data base contains statistics for average daily consumption (in fresh weight grams per kilogram of body weight per day). For estimates of MEI exposure, the consumption data for a non-nursing infant are used. This level of consumption is unlikely to be maintained over a lifetime and will yield a conservative estimate of risk. However, the TAS database reports average consumption rates for several age groups and does not represent individuals with unusually high consumption rates per unit of body weight. Therefore, the conservative method described above was chosen to compensate for outlying high individual rates of consumption that are not represented by TAS data.

As a less conservative alternative to the consumption rates of a non-nursing infant, the consumption rates listed in TAS as the average consumption for the U.S. population (48 states, all seasons) could be used to estimate risk. Replacing non-nursing infant consumption rates with U.S. average consumption rates decreases the estimates of MEI risk from the dietary pathway (land application disposal method) by approximately a factor of two.

The consumption rates used in each case are listed below.

	non-nursing infant (mg/kg/day)	U.S. average (mg/kg/day)
wheat	1031	1411
corn	693	408
beef fat	191	372
dairy fat	1424	429
pork fat	146	208
chicken	508	379
soybean oil	1359	322
fish	59	253

The TAS consumption value used for soybeans is that given for "soybean oil" since no value for "soybeans" is given. However, soybean oil consumption probably approximates soybean consumption since most human consumption of soybeans is in the form of oil. Since TAS does not break down fish consumption by species of fish, the analysis assumes that all fish consumed by the MEI is catfish. Beef, pork, and dairy consumption values include only the animal product fat, since the TCDD concentrations are calculated for animal fat. Pork, beef, and milk fat consumption values are given in TAS. Chicken total consumption values are taken from TAS and then reduced by multiplying by percent fat (NCASI, 1987). Since the fish BCF calculates the concentration in muscle (filet), no adjustment is made to the fish consumption figure.

Data Sources and Model Inputs for Animal Product Fat Percentages

As discussed above, chicken fat percentages are needed in the MEI estimate to convert chicken consumption to chicken fat consumption. In addition, animal product fat percentages are used in the population exposure estimates to convert from total animal production units grown on contaminated land to animal fat production units grown on contaminated land. This conversion is necessary since bioconcentration factors reflect the concentration in the animal product fat, except for catfish.

Kimbrough et al. (1984) gives beef fat percentages at between 8 and 12 percent; pork fat between 6 and 8 percent; and milk fat at 4 percent. The National Council of the Paper Industry for Air and Stream Improvement uses a milk fat percent of 3.7% and a beef fat percent of 12% (NCASI, 1987). The State of Wisconsin Department of Natural Resources suggests 12.6% beef fat, 4% dairy fat, 8% hog fat, and 10% chicken fat. The animal product fat percentages used in this analysis are listed in Table 2.4.F. for typical individuals and 2.4.G for the MEI.

Data Sources and Percent of MEI Diet that is Home-Grown

MEI consumption estimates are adjusted to reflect the percentage of the diet which is grown on sludge-amended land. The MEI is defined as a rural farmer applying sludge to all crops that are assumed in this analysis to be grown on sludge-amended land. The farmer is also assumed to feed the crops to all animal species that consume contaminated food according to this analysis.

The MEI is assumed to obtain only a portion of food consumed from her or his farm. U.S. EPA has estimated the percent of annual consumption which is homegrown for various foods for rural farm households (U.S.D.A. 1966, cited in U.S. EPA, 1988b). These data are used in this analysis and are presented in Table 2.4.G.

Data Sources and Model Inputs for Bioavailability

Human exposures are adjusted for bioavailability of the contaminant via ingestion. The bioavailability of 2,3,7,8-TCDD for fatty or oily foods and for other foods is estimated by U.S. FDA (1989). This analysis uses the ranges of bioavailability given by FDA for the "low" and "high risk" estimates and the midpoint of the range for the "best estimate" in the typical individual scenarios. The high value given by FDA is used in both the "best estimate" and "high risk" MEI scenarios.

Data Sources and Model Inputs for Population to which Contaminated Produce is Distributed

To determine typical exposures, total available quantity of contaminated food is divided by the population across which the crop or animal product is distributed. Though this calculation indicates the population at risk, the distribution population will not affect total population cancer risk (assumed to be a linear function of dose) since the total pollutant dose has already been determined. According to the county extension agent in one of two Mississippi counties applying sludge to agricultural land, the grains from the counties are distributed nationally. The Mississippi Cattle Industry Board stated that beef cattle are also distributed nationally. Catfish, chicken, and hogs produced in Mississippi are assumed to be nationally distributed. The only sludge-amended agricultural products from Pennsylvania are dairy products. Pennsylvania dairy products are generally distributed throughout the New England and Mid-Atlantic regions according to the Harrisburg Department of Agriculture. The estimated sizes of the populations to which contaminated animal products and crops are distributed are shown in Table 2.4.F.

2.4.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge

Direct ingestion of soil can occur when sludge is applied to sites where people may live and work, such as a family farm. To model the risks from the direct ingestion of sludge contaminated with TCDD and TCDF, this analysis adapts a model developed by Hawley (1985) which accounts for differences in exposure to indoor and outdoor concentrations of soil contaminants. Children ingest far more soil on average than adults; however, adults may also inadvertently ingest soil that adheres to food or cigarettes.

Description of Calculations

The calculation of risks from direct ingestion of soil is straightforward. First, the soil concentrations outdoors and the dust concentration indoors are estimated. The outdoor contaminant concentration is multiplied by the quantity of dirt consumed outdoors, while the indoor contaminant concentration is multiplied by the quantity of indoor dust ingested daily. Risk is estimated based on the daily quantity of soil and dust ingested, the gastrointestinal absorption of TCDD and TCDF from soil, and the cancer slope factors of TCDD and TCDF.

Description of Calculations for Estimating Exposure

The concentrations of TCDD and TCDF in outdoor soil are estimated as described in Appendix A. To obtain an estimate of indoor dust contaminant concentrations, the following calculation is performed:

$$C_{in} = C_o F$$

where :

C_{in} = concentration of contaminant in indoor dust, mg/kg

C_o = concentration of contaminant in outdoor soil, mg/kg

F = ratio of the contaminant concentration in indoor dust to the contaminant concentration in outdoor soil

Once the indoor dust and outdoor soil contaminant concentrations are computed, the daily dose of contaminant is calculated for persons in three age groups: young children (ages 1-6), older children (ages 7-11), and adults (ages 12 and older). The daily dose is calculated as:

$$DOSE_g = [(C_o \; DC_g \; F_{g,out}) + (C_{in} \; DC_g \; F_{g,in})] \; AB_g / BW_g$$

where:

AB_{gi} = systemic absorption rate from gastrointestinal tract (expressed as a fraction)
BW_g = body weight of individual in age group g
C_o = concentration of contaminant in soil, mg/kg
C_{in} = concentration of contaminant in indoor dust, mg/kg
DC_g = daily soil ingestion rate for individual in age group g, g/day
$DOSE_g$ = daily dose to individual in age group g, mg/kg/day
$F_{g,in}$ = fraction of ingested soil from indoor sources, adult
$F_{g,out}$ = fraction of ingested soil from outdoor sources, older child

First, for each age group, the concentration of TCDD or TCDF in outdoor soil is multiplied by total quantity of soil ingested each day and by the fraction of ingested soil from outdoor sources for that age group. The same calculations are performed for indoor dust ingestion. The total daily quantity of ingested soil-bound TCDD or TCDF is the sum of the indoor and outdoor quantities ingested. The model then adjusts the total quantity of ingested soil-bound TCDD or TCDF by the fraction absorbed into the system through the gastrointestinal tract, and divides by the body weight of an individual in that age group to obtain an average daily dose in mg/kg/day for that age group.

The weighted average daily dose of contaminant over an individual's lifetime is calculated as the sum of the daily doses for each age group weighted by the fraction of the individual's lifespan spent as a member of that age group, as described in the following calculation:

$$DOSE_{avg} = \Sigma \, F_g \, DOSE_g$$

where:

$DOSE_{avg}$ = average daily dose over lifetime, mg/kg/day
$DOSE_g$ = daily dose for individual in age group g, mg/kg/day
F_g = fraction of an individual's lifetime spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with the cancer slope factors of TCDD and TCDF to obtain an estimate of lifetime risk from direct ingestion exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg} \; q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC \;\; POP / LS$$

where:

LS = average lifespan of an individual = 70 years
PC = population risk, cancer cases per year
POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs

The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.4.I. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.4.J. The best MEI exposure estimate is derived by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Table 2.4.1. Assumptions and Parameter Values for a Typical Individual - Land Application: Soil Ingestion Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Amount soil ingested, g/day, child	0.1	0.2	0.2	0.1 to 0.2 given by OSWER as the range of "average values" for soil ingestion for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day, older child	0.1	0.1	0.2	0.1 to 0.2 given by OSWER as the range of "average values" for children; however, we used the lower end of this range, 0.1 g/d, as our best estimate for older children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day adult	0.001	0.02	0.1	0.001 to 0.1 given by OSWER as the range of values for adults; OSW suggested use of 0.02 as best estimate value.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Percent of daily ingestion from outdoors, child	0.545	0.545	0.875	Table 4-1 from EPA, 1988 shows summary of Hawley (1985) analysis of soil ingestion. The values presented in this table were converted to percentages. The high value is taken from value for older children.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Percent of daily ingestion from outdoors, older child	0.545	0.875	0.93	Percentage derived from Table 4-1, EPA, 1988. Low value is taken from estimate for younger children, high value from estimate for adults.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Percent of daily ingestion from outdoors, adult	0.875	0.93	1.0	Percentage derived from Table 4-1, EPA, 1988. Low value is taken from estimate for older children, high value is maximum percentage possible.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)

Table 2.4.1. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Soil Ingestion Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Amount of soil ingested from sludge-amended land	0.01	0.10	1.0	Value of 10% was used in evaluation of reuse of municipal sewage sludge. Low and high values arbitrary.	EPA, OWRS, "Human Health Risk Assessment for Municipal Sludge Disposal; Benefits of Alternative Regulatory Options," 1989.
GI absorption rate for soil	0.20	0.45	0.55	Low value used as estimate in "Estimating Exposures to 2,3,7,8-TCDD;" best estimate and high values from range suggested by Bioavailability Workgroup, based on review of studies.	Low: Schaum, 1984 Best, high: "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA.
Soil concentration indoors as function of outdoor concentration	Indoor = 75% outdoor	Indoor = 80% outdoor	Indoor = 85% outdoor		Hawley, 1985

Table 2.4.J. Assumptions and Parameter Values for the Most Exposed Individual - Land Application: Soil Ingestion Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Amount soil ingested, g/day, child	0.8	0.8	Highest value for soil ingestion for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day, older child	0.8	0.8	Highest value for soil ingestion for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day adult	0.10	0.10	0.1 given as highest value for adults.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Percent of daily ingestion from outdoors, child	100%	100%	Assumes all soil from outdoor sources.	
Percent of daily ingestion from outdoors, older child	100%	100%	Assumes all soil from outdoor sources.	
Percent of daily ingestion from outdoors, adult	100%	100%	Assumes all soil from outdoor sources.	

Table 2.4.J. Assumptions and Parameter Values for the Most Exposed Individual - Land Application: Soil Ingestion Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Amount of soil ingested from sludge-amended land	1.0	1.0	Assumes all soil from sludge amended area.	
GI absorption rate for soil	0.70	0.70	Highest values from range suggested by Bioavailability Workgroup, based on review of studies.	From: "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA
Soil concentration indoors as function of outdoor concentration	Indoor = 80% outdoor	Indoor = 85% outdoor		Hawley, 1985

Data Sources and Model Inputs for Soil Concentrations

The methods for deriving the soil concentrations for each land application site are presented in Appendix A. The resulting average soil concentrations over 70 years are displayed in Table 2.4.A.

Data Sources and Model Inputs for Soil Ingestion Rates

To be consistent with other EPA program offices, the typical and MEI analyses uses the soil ingestion rates found in the memo "Interim Final Guidance for Soil Ingestion Rates," (EPA, 1989a). This interim final guidance memorandum gives a suggested range of soil ingestion rates for children of 0.1 to 0.2 grams per day, with a maximum of 0.8 grams per day. The guidance memorandum based the suggested soil ingestion range for children on studies by Binder et al. (1986) and Clausing (1987); both of these groups of researchers studied soil ingestion in children with the use of tracer elements, such as aluminum, silicon, and titanium. The guidance memorandum suggests the use of 0.2 g/day as a best estimate of daily soil ingestion for children. The typical exposure analysis follows the guidance memorandum and uses the range given for young children, but uses as a best estimate of 0.1 grams/day for older children. The MEI analysis uses an ingestion rate of 0.8 g/day, as suggested by the guidance memorandum.

The OSW guidance memorandum gives a range for adult soil ingestion of 0.001 to 0.1 grams per day, based on work by Calabrese et al. (1987), as cited in the OHEA Draft Exposure Factors Handbook (May 1988). In accordance with OSW policy, the typical exposure analysis uses 0.02 grams per day as the best estimate of daily soil ingestion by adults, while using 0.001 and 0.1 to represent the low and high estimates. The MEI adult is assumed to ingest 0.1 grams per day.

Data Sources and Model Inputs for Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

This analysis assumes that the concentration of TCDD and TCDF in indoor dust is related to the concentration of TCDD and TCDF in outdoor soil. Values for this parameter are derived from Hawley (1985), who assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The typical exposure analysis uses a value of 80% as a best estimate, and applies a range of 75% to 85% as the low and high estimates, respectively. The MEI "best" estimate calculation uses a value of 80% for this parameter, while the "high risk" MEI estimate uses a value of 85%.

Data Sources and Model Inputs for Fraction of Soil Ingested from Outdoor and Indoor Sources

The fraction of soil ingested indoors and outdoors is multiplied by the total daily ingestion rates used by EPA (1989a) to obtain the quantities of soil ingested indoors and outdoors each day. To obtain an estimate for this input parameter, the typical exposure analysis relies on information from EPA (1988a). EPA (1988a) presents a summary of the work of Hawley (1985), who estimated the dust/soil quantities ingested indoors and outdoors from the dermal soil contact rate and from the area of skin that comes in contact with food, cigarettes, or objects mouthed by children. Although the Hawley (1985) estimates of the total grams per day ingested differ slightly from those used in this analysis, the summary of these values presented in EPA (1988a) is used to estimate the relative fraction of total ingested soil contributed from indoor and outdoor sources. For all age groups, a larger fraction of the total daily quantity of soil ingested comes from outdoor sources, due to the larger dermal soil contact rates outdoors that lead to larger ingestion rates. Young children have the largest proportion of total soil/dust ingestion from indoor sources. As a person ages, the relative proportion of soil from outdoor sources increases, due to the decline in the amount of dust ingested while indoors.

The typical exposure assessment uses the data for each age group from Hawley (1985), as presented in EPA (1988a), for calculating the "low risk" and "best" estimates of typical exposure. For the "high risk" estimate of typical exposure, the fraction of soil ingested outdoors for young children is assumed to be the same as the "best" estimate for older children; similarly, the value used in the "high risk" estimate for older children is the same as the value used in the "best" estimate for adults. For adults, the "high risk" estimate of typical exposure assumes that all of the soil ingested each day is from outdoor sources. In the MEI analysis, for all three age groups, the total quantity of soil ingested by the MEI is assumed to originate from outdoor sources.

Data Sources and Model Inputs for Fraction of Ingested Soil from Contaminated Area

The sludge-amended land application site is only one among may potential sources of ingested soil. Soil may be ingested at locations removed from the contaminated site, such as a playground or an outdoor workplace. The fraction of the total quantity of ingested soil originating from the portion of the yard or farm treated with TCDD- or TCDF-contaminated sludge may be quite small. However, there is no information available regarding what this fraction may be. In the absence of data, the typical exposure assessment assumes that 10% of the total soil ingestion daily is from sludge-amended land, and uses an arbitrary range of 1% to 100% to represent the low and high estimates for this model parameter. The MEI analysis assumes that all of the soil ingested by the MEI originates from the sludge-amended area. These assumptions are the same as those used in the analysis of risks from direct soil ingestion from land treated with municipal sewage sludge (EPA, 1989b).

Data Sources and Model Inputs for Absorption Through GI Tract

Absorption of TCDD and TCDF through the gastrointestinal tract has been studied using a variety of media. Absorption will be influenced by how tightly TCDD or TCDF binds to the matrix in which it is ingested. Poiger and Schlater (1980), as cited in Schaum (1984) reported that the gastrointestinal bioavailability from soil in their studies was 20% to 26%. In a recent review of the literature, FDA (1989) discussed an experiment by Bonaccorsi et al. (1984), who found that G.I. bioavailability of TCDD from freshly "spiked" soil was 56-74%. Umbreit et al. (1988) found lower bioavailability from an environmentally contaminated site, demonstrating that aging of the soil affects bioavailability. Furthermore, McConnell et al. (1984) found that environmentally contaminated soil samples were 24-32% as bioavailable as TCDD in a corn oil matrix or a freshly "spiked" soil matrix. As a result, FDA (1989) recently concluded that a reasonable estimate for absorption from ingested soil is in the range of 45-55%. This range is used for the "best" and "high risk" estimates in the typical exposure assessment, while a value of 20% is adopted for the low estimate. For the MEI analysis, a gastrointestinal absorption rate of 70% is assumed, which is in the high end of the range cited in the FDA literature review.

Data Sources and Model Inputs for Estimating the Population Exposed

In this analysis, the population exposed to TCDD and TCDF through dermal contact is limited to the population residing on the agricultural land application sites. The number of sites applying kraft mill sludge to land is equal to the total number of acres applied with sludge in the state divided by the average number of acres per site. Values for both the total acres and the acres per site were obtained through conversations with state officials in Mississippi and Pennsylvania, the states where agricultural land application is currently practiced. In Mississippi, 1000 acres are applied with the sludge from one mill, with an estimated 100 acres per site, yielding an estimate of 10 sites in Mississippi. Pennsylvania has 75 acres covered with sludge from one mill, with an average of 15 acres per site, giving a total of 5 sites. The total number of sites in each state is multiplied by the number of people living on each site to obtain the exposed population. According to the 1980 U.S. Census, the average number of persons per household is 2.7. In Pennsylvania, the exposed population is approximately 14 persons, while in Mississippi, the exposed population is approximately 27. The total exposed population is about 40 persons.

2.4.4 Estimates of Exposures and Risks from Inhalation of Sludge-Contaminated Particulates

TCDD and TCDF adhering to soil particles can become suspended in the air near a land application site. Transport downwind will dilute the concentration of particles from a land application site; these particles will also redeposit on surfaces. Residents living on or near the land application sites may be exposed to TCDD or TCDF by inhaling these particles. This section describes the methods used to estimate the emissions of particles from a land application site and the subsequent human exposure to these emissions. This analysis only considers exposure to inhaled particulates for residents onsite.

To estimate the suspended particulate concentration at land application sites, the methodology presented in Estimating Exposures to 2,3,7,8-TCDD (EPA, 1988a) is used for estimating emissions due to wind erosion. Although other models for emissions from intermittent, short-term sources, such as spreading operations and vehicular traffic, were also presented, the model for emissions from wind erosion was chosen, since the analysis focusses on average exposures over the long-term. EPA (1988a) describes the assumptions underlying the model as follows: "This method assumes that the uncrusted contaminated surface is exposed to the wind and consists of finely divided particles. This creates a condition defined ... as an "unlimited reservoir" and results in maximum wind-caused dust emissions." (p.66). The model incorporates information on wind speed and percent vegetation cover to estimate the flux of small particles (i.e., less that 10 um) from an area of land. Soil amended with paper mill sludge may not have the characteristics assumed by the model; to the extent that the surface of a sludge-amended site consists of crusted, coarser particles, the model is likely to overestimate emissions.

To obtain particulate concentration, the calculated emission rate is used as input to a box model of atmospheric mixing. The box model ignores any atmospheric dispersion downwind, and is only appropriate for estimating onsite concentrations. The model uses wind speed, size of the site and the mixing height to yield an onsite particulate concentration (EPA (1988a), Equation 4-7).

As an alternative approach to estimating onsite particulate concentration, the model described by Hawley (1985) is applied; this model uses measured values of total suspended particles adjusted by the fraction of particles assumed to be derived from local (contaminated) soils to derive the onsite concentration of contaminated suspended particulates.

The calculation of risks from inhalation of particles requires several steps. First, the emissions of particles from the treated area is estimated. Next, the indoor and outdoor concentrations of particles onsite are calculated. The concentrations are combined with information about the length of time spent indoors and outdoors, respiratory rate, and the cancer slope factors of TCDD and TCDF to yield the estimated cancer risks.

Description of Calculations Used to Estimate the Concentration of TCDD and TCDF in Particulates

The first step in this calculation is to estimate the emissions of particulates from the treated area as follows:

$$E = 0.036\,(1-V)(Um/Ut)^3\ F(x)$$

where:

E = emission rate, g/m^2 hr

V = fraction vegetative cover

Um = windspeed, m/s

Ut = threshold wind speed (wind velocity at height of 7 meters above the ground needed to initiate erosion)

$F(x)$ = function specific to the model, described in EPA (1988a), where F(x) is estimated by first calculating $x = 0.886\,(Ut/Um)$

This equation gives the flux of dust particles from the surface as a function of 1) the vegetative covering of the surface and 2) the cube of the ratio of the windspeed to the threshold wind velocity (the velocity required to initiate erosion). F(x) is a function that is specific to this model. The value of x is calculated as a function of the ratio of threshold wind speed to the wind speed.

Once the value of x is calculated, F(x) can be determined by reading the value from the graph of the function presented in EPA, OAQPS (1985, as cited in EPA, 1988a).

To convert the dust flux to a contaminant emission rate, the following formula is used:

$$Q = C_sEA\ (1\ \text{hour}/3{,}600\ \text{seconds})$$

where:

Q = contaminant emission rate in mg/s

C_s = contaminant concentration in the soil, mg/g

E = flux, g/m^2 hr

A = area of the treated site, m^2

The next step is to estimate the concentrations of particulates on the land-treatment site. Both outdoor concentrations and indoor concentrations must be calculated. The outdoor concentration is derived as follows:

$$C_o = Q/(L\ MH\ V)$$

where:

C_o = contaminant concentration in suspended particles onsite outdoors, mg/m^3
Q = emissions in mg/sec
L = length of one side of the treated area, m
MH = mixing height (assumed to be 1.5 meters)
V = wind speed at mixing height, m/s, assumed to be 2.2 m/s

An alternative method of calculating outdoor contaminant particulate concentrations is to adjust the measured TSP concentration at the site by the fraction believed to originate from local (contaminated) soils (Hawley, 1985). This method is described by the following equation:

$$C_o = TSP\ FL\ C_s$$

where:

C_o = concentration of suspended particles outdoors originating from sludge-amended land, mg/m^3
C_s = concentration of contaminant in soil, mg/kg
FL = fraction of total suspended particles assumed to originate from local (contaminated) sources
TSP = measured total suspended particle concentration, mg/m^3

Regardless of the method used to estimate outdoor contaminant particle concentrations, the indoor concentrations are derived using the following equation:

$$C_{in} = C_o\ R\ F$$

where:

C_{in} = indoor contaminant concentration, ng/m^3
C_o = outdoor particulate concentration, ng/m^3
R = ratio of indoor particulate concentration to outdoor particulate concentration
F = ratio of the concentration in indoor dust to the concentration in outdoor soil

First, the indoor suspended particle concentration is derived by applying the ratio of suspended particulate concentration indoors to the suspended particulate concentration outdoors. Next, since only a portion of indoor suspended dust is assumed to originate from outdoor sources (the rest is derived from smoking, cooking, etc.) the contaminant concentration in indoor dust is adjusted by a fraction representing the ratio of indoor dust contaminant concentration to the outdoor soil contaminant concentration.

Description of Calculations Used to Estimate Human Exposure to Particulates

Once the concentration of contaminants in particulates is estimated, human exposure to contaminated particulates can be estimated. In the "high risk" estimate of typical exposure, and in the "high risk" MEI analysis, the particulate concentration was estimated based on total particulates using Hawley (1985). When calculating exposure from this method of estimating particulate concentration, the first step is to determine the concentration of particles that are respirable. The respirable concentration is estimated as:

$$RC_o = C_o \, FR$$

$$RC_{in} = C_{in} \, FR$$

where:

C_o = concentration of TCDD or TCDF in suspended particles outdoors, mg/m^3
C_{in} = concentration of TCDD or TCDF in suspended particles indoors, mg/m^3
FR = fraction of suspended particles that are respirable
RC_o = respirable particulate concentration outdoors, mg/m^3
RC_{in} = respirable particulate concentration indoors, mg/m^3

In the "low risk" and "best" estimate calculations for typical exposure, the EPA (1988a) method is used to estimate emissions of contaminant adhering to respirable particles (that is, all of the emissions are assumed to be respirable). Therefore, these estimates need no further adjustment.

The next step in the calculation of human exposure to TCDD and TCDF through the inhalation of particulates is the estimation of the daily dose. The daily dose is calculated for three age groups: young children (ages 1-6), older children (ages 7-11), and adults (ages 12 and older).

$$DOSE_{o,g} = [(RC_o \, D_l \, AB_l \, H_{o,g}) + (RC_o \, D_{gi} \, AB_{gi} \, H_{o,g})] \, V_g \, / \, BW_g$$

$$DOSE_{i,g} = [(RC_{in} \, D_l \, AB_l \, H_{i,g}) + (RC_{in} \, D_{gi} \, AB_{gi} \, H_{i,g})] \, V_g \, / \, BW_g$$

where:

AB_l = systemic absorption rate through the lung
AB_{gi} = systemic absorption rate through the gastrointestinal tract
BW_g = body weight of individual in age group g
D_l = fraction of respired particles retained by the lung
D_{gi} = fraction of respired particles swallowed (fraction of particles to gastrointestinal tract)
$DOSE_{o,g}$ = dose to individual in age group g, outdoors, mg/kg/day
$DOSE_{i,g}$ = dose to individual in age group g, indoors, mg/kg/day
$H_{i,g}$ = hours spent indoors for individual in age group g
$H_{o,g}$ = hours spent outdoors for individual in age group g
V_g = weighted average ventilation rate for individual in age group g, m^3/day

In this equation, the concentration of the contaminant adhering to particles is multiplied by the volume of air inhaled each day and by the fraction of the day spent outdoors. Similarly, the quantity of particulates inhaled indoors each day is the product of the indoor respirable concentration, the volume of air inhaled each day, and the fraction of the day spent indoors. The total quantity of particles inhaled each day is then partitioned between the lung and the gastrointestinal tract. A gastrointestinal absorption fraction is then applied to the portion swallowed, while a respiratory absorption fraction is applied to the portion remaining in the lung.

A weighted average dose for an individual over the entire lifetime can be derived by weighting the daily dose received during each age interval by the fraction of the individual's lifespan spent in that age group. This calculation is described in the following equation:

$$DOSE_{avg} = \Sigma\,(DOSE_{o,g} + DOSE_{i,g})\,F_g$$

where:

$DOSE_{avg}$ = weighted average daily dose over lifetime, mg/kg/day
$DOSE_{o,g}$ = dose to individual in age group g, outdoors, mg/kg/day
$DOSE_{i,g}$ = dose to individual in age group g, indoors, mg/kg/day
F_g = fraction of lifespan spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with the human cancer slope factors of TCDD and TCDF to obtain an estimate of lifetime risk from particulate inhalation to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg}\ q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day

IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF

q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the typical individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC\ POP / LS$$

where:

LS = average lifespan of an individual = 70 years

PC = population risk, cancer cases per year

POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs

The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.4.K. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.4.L. The best MEI exposure estimate is derived by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for the Wind Erosion Flux Calculation

The present analysis follows the calculations of EPA (1988a) to calculate wind erosion, and uses many of the input parameters used in the sample calculations in that document. These inputs are briefly described below.

Table 2.4.K. Assumption and Parameter Values for a Typical Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11 assuming 90% vegetative cover	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Low: calculated using Eq. 6-11 from EPA 1988, assuming 90% vegetation Best estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation High: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.70	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Percent TSP respirable	NA	NA	0.90	Our low and best estimates for emissions are from Eq. 6-11 (EPA, 1988), which gives estimates of small (<10 um) particle emissions. All of these particles are assumed to be respired. The value given here applies only to TSP, which consists of large and small particles (i.e., this parameter applies only to our high estimate of emissions).	Hawley, 1985
Fraction of TSP to lung	1/6 of respired particles	1/3 of respired particles	1/3 of respired particles	Best and high: 1/3 of particles in lungs. Low: after 24 hrs 1/2 of 1/3 is swallowed.	Schaum, 1984 (citing ICRP, 1968)
Fraction of TSP to GI tract	2/3 of respired particles	2/3 of respired particles	5/6 of respired particles	Low and best: 2/3 respired particles in GI; high: one-half of particles in lungs is swallowed within 24 hours.	Schaum, 1984 (citing ICRP, 1968)
Absorption rate, lung		1.0		Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 2.4.K. (con't.) Assumption and Parameter Values for a Typical Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Absorption rate, GI ingested	0.20	0.45	0.55	Low from Schaum citing Polger and Schlatter study (1980). Best and high from Bioavailability Workgroup review of studies.	Schaum, 1984. "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA.
Hours per day and number of days spent outdoors, adult	8 hrs/day 40 days	12 hrs/day 130 days	12 hrs/day 130 days	Low: assumes adult works 2 days per wk for 5 months outdoors, 8 hrs/day Best and high: 6 months, 5 days/wk, 12 hrs/day.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	8 hrs/day 130 days	8 hrs/day 130 days	12 hrs/day 182 days	Low and best: assumes child plays outdoors 8 hrs/day, May-October, 5 days per wk High: assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	5 hrs/day 152 days	5 hrs/day 152 days	12 hrs/day 152 days	Low and best: assumes child plays outdoors an average of 5 hrs/day, May-September High: assumes 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult attic, living space	12 hrs/yr in attic; 16 hrs/day, 365 days living space	12 hrs/yr, in attic; 12 hrs/day, 130 days plus 24 hrs/day, 235 days	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic; Living space: Low: 12 hrs/day, 365 days in living space Best and high: 12 hrs/day in living space for 130 days in summer months plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 2.4.K. (con't.) Assumption and Parameter Values for a Typical Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	12 hrs/day 182 days, plus 24 hrs/day, 182 days	16 hrs/day, 130 days, plus 24 hrs/day, 235 days	16 hrs/day 130 days, plus 24 hrs/day 235 days	Low: assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day Best and high: assumes indoors 16 hrs/day, 5 days/wk during May-October, indoors 24 hrs/day for remainder of days. (Note: Low indoor estimate coupled with high outdoor estimate.)	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	12 hrs/day 152 days plus 24 hrs/day for 213 days	16 hrs/day for 365 days	16 hrs/day for 365 days	Low: assumes child is indoors 12 hrs/day, 7 days/wk, 24 hr/dy for 5 months. Best and high: assumes child is indoors an average 16 hrs/day. (Note: Low indoor estimate coupled with high outdoor estimate.)	Adopted from Hawley, 1985
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 75% outdoor	Indoor = 80% outdoor	Indoor = 100% outdoor	Low and best: From Hawley, 1985 High estimate is maximum value possible.	Hawley, 1985

Table 2.4.L. Assumption and Parameter Values for the Most Exposed Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Best estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation High: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 80% outdoor	Indoor = 100% outdoor	Best: From Hawley, 1985 High estimate is maximum value possible.	Hawley, 1985
Percent TSP respirable	(NA)	0.90	The value given here applies only to TSP, which consists of large and small particles (i.e., this parameter applies only to our high estimate of emissions, for which we used the 0.90 value).	Hawley, 1985
Fraction of TSP inhaled to lung	1.00	1.00	All is absorbed through the lung.	
Fraction of TSP inhaled to GI tract	0	0	All is absorbed through the lung.	
Absorption rate, lung	1.0		Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 2.4.L. Assumption and Parameter Values for the Most Exposed Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Absorption rate, GI Ingested	NA	NA	Not applicable to MEI, since all particles are absorbed by lung.	
Hours per day and number of days spent outdoors, adult	12 hrs/day 130 days	12 hrs/day 130 days	6 months, 5 days/wk, 12 hrs/day.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	12 hrs/day 182 days	12 hrs/day 182 days	Assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	12 hrs/day 152 days	12 hrs/day 152 days	Assumes 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult attic, living space	12 hrs/yr, in attic; 12 hrs/day, 130 days plus 24 hrs/day, 235 days in living space	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days in living space	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic; Living space: 12 hrs/day in living space for 130 days in summer months plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 2.4.L. Assumption and Parameter Values for the Most Exposed Individual - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	12 hrs/day, 182 days plus 24 hrs/day 182 days	12 hrs/day, 182 days plus 24 hrs/day 182 days	Assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	12 hrs/day 152 days plus 24 hrs/day for 213 days	12 hrs/day 152 days plus 24 hrs/day for 213 days	Assumes child is indoors an average 12 hrs/day from May-September, and is indoors for the rest of the year 24 hrs/day.	Adopted from Hawley, 1985

Vegetative cover is assumed to be 50% for the land application sites, since these sites are used for agricultural application; the sites are assumed to be bare for about half of the year, and covered with crops for one-half of the year. This assumption is used for the "best" estimate of exposure and for the "best" estimate of MEI exposure. For the emissions estimate in the "low risk" typical exposure analysis, 90% vegetative cover is assumed.

Mean annual windspeed is 4 meters per second. This is the average windspeed at a height of 10 meters for 60 major cities in the United States (EPA, 1988a).

The threshold wind speed can be derived if the roughness height and the threshold friction velocity of the surface are known. EPA (1985, as cited in EPA (1988a)) describes the ratio of threshold wind speed to friction velocity as a function of roughness height. The threshold friction velocity for unlimited reservoir surfaces is less than 75 cm/s (EPA, 1988a). Based on this information, EPA (1988a) adopted a value of 50 cm/s for this type of surface. The present analysis also uses this value for threshold friction velocity at sludge land application sites. For the roughness height of an agricultural land application site, a value of 2 cm is used, which corresponds to a field with grass cover. The ratio of threshold wind speed to threshold friction velocity for a roughness height is derived from tables provided in EPA (1985), as cited in EPA (1988a). For a roughness height of 2 cm, the ratio is 15. To obtain the threshold wind speed, this ratio is multiplied by 50 cm/s, the assumed value for the threshold friction velocity. The resulting value is 7.5 m/s.

The value for the function F(x) can be obtained from a graph of the function found in EPA (1985), as cited in EPA (1988a). First, the value of x must be calculated. For a site with a threshold wind speed of 7.5 m/s, the estimate is 0.886 x [(7.5 m/s)/(4 m/s)], or 1.66. From the graph provided in EPA (1985), cited by EPA (1988a), the value of $F(x)$ for $x = 1.66$ is 0.65.

Data Sources and Inputs for TSP Concentrations

As an alternative to the wind erosion dust flux calculation, the method used by Hawley (1985) is used in calculating the "high risk" estimate of typical exposure, and in calculating the "high risk" estimate of MEI exposure, since the result derived by this method is higher than the result using the wind erosion dust flux equation. This method bases the estimate of particulate concentrations on measured values of total suspended particles (TSP). The annual geometric mean values for suspended particle concentrations for SMSAs of between 500,000 and 1 million people were obtained from National Air Quality Trends Report, 1982 (EPA, 1984). The average value for these areas is 64 ug/m^3. This value is similar to the value of 70 ug/m^3 used by Hawley (1985). This value is then adjusted by the percent of suspended particles derived from local soils, assumed to be 50 percent (Hawley, 1985).

Data Sources and Model Inputs for Soil Concentrations of TCDD and TCDF

The estimated soil concentrations for each land application site are displayed in Table 2.4.A. The methods used to derive these concentrations is discussed in detail in Appendix A.

Data Sources and Model Inputs for Deriving Indoor Airborne Particle Concentration as a Function of Outdoor Particulate Concentration

Hawley (1985) compared several studies that investigated the relationship between indoor particle concentrations and outdoor particle concentrations. Whitby et al. (1957), as cited by Hawley (1985), found that, for the City of Niagara Falls, New York, the indoor suspended particulate concentration was 65 ug/m^3 and the outdoor particulate matter concentration was 93 ug/m^3. This yields an indoor to outdoor ratio of approximately 0.70. Sterling and Kobayashi (1977), also cited in Hawley (1985), found that this ratio ranged from 0.77 to 0.85. In the typical exposure assessment, the value 0.75 is used as the best estimate of this ratio, while 0.70 and 0.85 are used as the low and high estimates, respectively. For the "best" MEI exposure estimate, a value of 0.75 is used, while the "high risk" MEI exposure assessment uses a value of 0.85 for this parameter.

Data Sources and Model Inputs for Deriving Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

Roberts et al. (1977), as discussed by Hawley (1985), studied the relationship between lead concentrations indoors and outdoors near a lead smelter, and found that the mean concentration of the lead in household dust was 75% of the concentration of lead in the outdoor soil. For his own analysis, Hawley (1985) assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The typical exposure analysis uses a value of 80% for the "best estimate", and applies a range of 75% to 100% for the "low" and "high" estimates, respectively. For the "best" MEI exposure estimate, a value of 80% is used, while the "high risk" MEI exposure assessment uses a value of 100% for this parameter.

Data Sources and Model Inputs for Estimating the Percent of Particulates that are Respirable

Deposition in the lung depends on the size of the particle. The typical exposure analysis uses a method of estimating emissions of particles less than 10 um in diameter to derive "best" and "low" estimates of the concentration of suspended particles at a land application site. The "best" MEI exposure estimate uses this value as well. Schaum (1984), presenting data from ICRP (1968), states that almost all particles less than 10 um are respirable. Therefore, for the "low" and "best" typical exposure estimates, all of the particles were assumed to be respirable. In the "high risk" typical exposure assessment, and in the "high risk" MEI exposure assessment, the concentration of suspended particles is derived from measured values of total suspended particles, a measurement which includes particles of various sizes. Therefore, the fraction of total suspended particles that will be deposited in the lung must be estimated. Hawley (1985) and Schaum (1984) both assumed that 75% of inhaled particles are retained in the body. For particles 0.2 to 20 um, ICRP (1979), as cited in Hawley (1985), indicates that the fraction deposited in the respiratory tract ranges from 60 to 90%. For the "high risk" typical and "high risk" MEI scenarios, it is assumed that 90% of TSP is respirable.

Data Sources and Model Inputs for Estimating the Fraction of Inhaled Particles Deposited in the Lung and in the Gastrointestinal Tract

Schaum (1984), citing ICRP (1968), discusses the distribution of inhaled particles within the body. Of the particles initially retained by the body, one-third remains in the lower sections of the lung, and two-thirds remain in the upper respiratory tract. Eventually, some particles in the respiratory tract are swallowed. After twenty-four hours, approximately one-half of the amount originally retained in the lower sections of the lung is swallowed. For the "best estimate" and "high risk" typical exposure scenarios, it is assumed that one-third of particles are retained in the lung for a sufficient length of time for systemic absorption of TCDD or TCDF to occur through the lung. For the "low risk" typical exposure scenario, this analysis assumes that only one-sixth of the particles are retained in the lung for a sufficient length of time for absorption through the lung to take place. The rest is swallowed and absorbed through the GI tract (which has a lower systemic absorption rate). In the MEI analysis, it is assumed that all respirable particles are retained long enough in the lung for systemic absorption through the lung to occur (that is, all of the contaminants adhering to respired particles that are absorbed are absorbed through the lung).

Data Sources and Model Inputs for Respiration Rate

Respiration rate is used in the model to assess the total daily volume of particles inhaled. For adults, the average respiration rate was calculated by EPA (1985b) to be 23 m^3 per day. This value was calculated using data on the ventilation rates during different levels of activity, and the amount of time spent per day engaging in these levels of activity, to obtain a daily total. For children, Hawley states that the ventilation rate of young children engaged in light activity is 7.6 l/min, while the ventilation rate during rest is 2.8 l/min; assuming children spend roughly one-third of their day engaged in light activity and two-thirds at rest, the total ventilation rate is 6.3 m^3 per day. For older children, the ventilation rate is 11.6 l/min during light activity and 4.3 l/min at rest (Hawley, 1985), with a total ventilation rate of 8.4 m^3 per day for both the typical exposure and the MEI exposure analyses.

Data Sources and Model Inputs for Estimating Absorption Through the Lung

Little data are available to estimate the systemic absorption of TCDD or TCDF through inhalation. Faced with a lack of information, U.S. EPA (1989d) assumed that TCDD is almost completely absorbed from respirable particles (i.e., those less than 10 um in diameter). This analysis follows this assumption, and assumes that 100% of the TCDD and TCDF adhering to respired particles is absorbed through the lungs for both the typical and MEI exposure analyses.

Data Sources and Model Inputs for Estimating Absorption through GI Tract

Absorption of TCDD and TCDF through the gastrointestinal tract has been studied using a variety of media. Absorption will be influenced by how tightly TCDD or TCDF binds to the matrix in which it is ingested. Poiger and Schlater (1980), as cited in Schaum (1984) reported that the bioavailability of TCDD from soil was 20-26%. In a recent review of the literature, FDA (1989) discussed an experiment by Bonaccorsi et al. (1984), who found that availability of TCDD from freshly "spiked" soil was 56-74%. The memorandum also cites a study by Umbreit et al. (1988), who found lower bioavailability from soil from an environmentally contaminated site, demonstrating that aging of the soil affects bioavailability. Also discussed was a study by McConnell et al. (1984), who found that environmentally contaminated soil samples were 24-32% as bioavailable as TCDD in a corn oil matrix or a freshly "spiked" soil matrix. As a result, FDA (1989) recently concluded that a reasonable estimate for absorption from ingested soil is in the range of 45-55%. This range is used for the "best" and "high risk" typical exposure estimates, while a value of 20% is adopted for the "low risk" typical exposure estimate. No gastrointestinal absorption of inhaled particles occurs for the MEI, since all absorption is assumed to occur through the lungs.

Data Sources and Model Inputs for Determining the Fraction of the Day Spent Indoors and Outdoors

In order to estimate exposure duration in indoor and outdoor settings, the methodology developed by Hawley (1985) to estimate the time spent outdoors and indoors by different age groups is adapted. For adults, Hawley (1985) also presented values for estimating exposure to dust while cleaning infrequently used spaces, such as attics, that have been incorporated into this analysis.

Young children have the most exposure to outdoor particulate concentrations. In the typical exposure analysis, these children are assumed to be outdoors 8 hours per day, five days per week from May to October. The remaining time is spent indoors on the site. For the "high risk" estimate of typical exposure, it is assumed that young children are outdoors for an average of six hours a day for the entire year, which is the equivalent of twelve hours per day, seven days a week for the six months out of the year. This assumption is also used for the most exposed young child.

Typical older children are assumed to spend an average of five hours per day from May to September outdoors. This value is the average of time spent outdoors after school on school days and time spent outdoors on weekends and on school vacation days. Older children are assumed to be indoors on the site for sixteen hours per day for the entire year. The remainder of the time is spent at another indoor location, such as school. For the "high risk" estimate of typical exposure, older children are assumed to be outdoors an average of 5 hours per day for the entire year, which is the equivalent of 12 hours per day for five months, and to be indoors on the site for the remainder of the time. This assumption is used for the most exposed older child analysis as well.

This analysis assumes that an adult living on an agricultural land application site (i.e., a farmer) works outdoors 5 days per week, 12 hours per day, for six months, and spends the rest of the time indoors on the site. This value is used in the typical exposure analysis for all but the "low risk" scenario, and is used in the MEI analysis. For the "low risk" typical exposure scenario, it is assumed that the adult resides on the farm, but works elsewhere; in this case, the adult is assumed to engage in outdoor activities onsite for 8 hours per day, two days a week from May to September, and to spend 16 hours per day indoors on the site all year long.

While indoors, adults may spent a limited amount of time in an extremely dusty area, such as an attic, where exposure to inhaled dust would be higher than in normal living spaces. Hawley (1985) estimated exposure to dust to be 20 mg during one hour in the attic, and assumed that adults are exposed at this level for twelve hours each year (either one day for 12 hours or one hour for twelve days). The current analysis incorporates these assumptions into both the typical and MEI exposure assessments.

Data Sources and Model Inputs for Estimating the Population Exposed

In this analysis, the population exposed to TCDD and TCDF through dermal contact is limited to the population residing on the agricultural land application sites. The number of sites applying kraft mill sludge to land is equal to the total number of acres applied with sludge in the state divided by the average number of acres per site. Values for both the total acres and the acres per site were obtained through conversations with state officials in Mississippi and Pennsylvania, the states where agricultural land application is currently practiced. In Mississippi, 1000 acres are applied with the sludge from one mill, with an estimated 100 acres per site, yielding an estimate of 10 sites in Mississippi. Pennsylvania has 75 acres covered with sludge from one mill, with an average of 15 acres per site, giving a total of 5 sites. The total number of sites in each state is multiplied by the number of people living on each site to obtain the exposed population. According the 1980 U.S. Census, the average number of persons per household is 2.7. In Pennsylvania, the exposed population is approximately 14 persons, while in Mississippi, the exposed population is approximately 27. The total exposed population is about 40 persons.

2.4.5 Estimates of Exposure and Risks from Inhalation of Vapors

Residents of land applications sites may incur risk from the inhalation of volatilized TCDD and TCDF. The methodology for estimating the emissions of TCDD and TCDF vapor at land application sites generally follows methods for estimating volatilization described in EPA (1988a). Because actual locations of the land application sites are not known, the ISCLT model could not be used to estimate downwind concentrations. As a result, this analysis estimates only exposures to onsite residents, using a box model to obtain the onsite concentrations from the emissions estimates.

The calculation of risks from the inhalation of vaporized TCDD or TCDF requires first the estimation of emissions, then the calculation of indoor and outdoor onsite concentrations. The concentrations are combined with data on time spent indoors and outdoors, respiration rate and the cancer slope factors of TCDD and TCDF to obtain the estimated cancer risk from this pathway of exposure.

Methods for Estimating Vapor Emissions

This analysis uses a set of equations from U.S. EPA (1986), and Hwang and Falco (1986) as described in U.S. EPA (1988a), to predict emissions from a land application site. It assumes that emissions from land application sites (in $g/m^2/s$) are described by:

$$N_a = \frac{2D_iE^{4/3}K_{as}C_s}{[\pi \alpha T]^{1/2}}$$

where:

$$\alpha = \frac{D_iE^{4/3}}{E + p_s(1-E)/K_{as}}$$

$$K_{as} = 41\ H_c/K_D$$

and:

D_i = the molecular diffusivity of contaminant vapor in air (cm/second)

C_s = the contaminant concentration in the soil (g/g),

E = effective porosity of soil, assumed to be 0.25 (unitless)

H_c = Henry's law constant (atm m^3/mol)

p_s = true density of soil, assumed to be 2.65 g/cm3

K_D = the soil/water partition coefficient (cm^3/g) = (organic carbon/water partition coefficient)(fraction of organic carbon in soil)

K_{as} = the air/soil partition coefficient (mg/cm^3 in air per mg/g in soil)

N_a = rate of emissions from the soil surface (g/m^2/second)

T = duration of exposure (seconds), assumed to be 2.2×10^9 seconds (70 years)

This equation uses information on the partitioning of TCDD and TCDF between soil and air and between water and soil to estimate emissions of TCDD and TCDF vapor per m^2 area. The emissions estimate is then multiplied by the area of the site, in m^2, to obtain the total emissions of vapor from the land application site:

$$Q = 1000\ N_a\ A$$

where:

Q = emissions rate for contaminant vapor, mg/s

A = area of the land application site, m^2

1000 = conversion from grams to milligrams

The emission rate is then coupled with a box model to obtain the onsite concentrations of vapor. Outdoor vapor concentrations are estimated as:

$$C_o = Q/(L\ MH\ V)$$

where:

C_o = concentration of vapor outdoors, mg/m^3
Q = emissions, mg/sec
L = length of one side of the treated area, m
MH = mixing height (assumed to be 1.5 meters)
V = wind speed at mixing height, m/s, assumed to be 2.2 m/s

The indoor vapor concentration is derived by applying the ratio of vapor concentration indoors to the vapor concentration outdoors, as described in the following equation:

$$C_{in} = C_o R$$

where:

C_{in} = indoor vapor concentration, ng/m^3
C_o = outdoor vapor concentration, ng/m^3
R = ratio of indoor vapor concentration to outdoor vapor concentration

It is assumed that the relationship between vapor concentrations indoors and outdoors is similar to the ratio between indoor and outdoor particulate concentrations (that is, indoor concentrations are approximately 75% of outdoor concentrations with a range from 70-85%).

Once the concentration of contaminant in the air is estimated, the calculation of exposure and risks from the inhalation of vapor then proceeds in the same manner as the exposure and risk from the inhalation of particles, described in section 2.4.4. Table 2.4.K. summarizes key assumptions and input parameters for estimating typical individual exposure through the vapor and particulate inhalation pathways, while Table 2.4.L. summarizes the inputs used in the MEI analysis. In some cases, the data inputs used for the estimation of exposure and risk are different than those used in section 2.4.4. The data inputs unique to the calculation of risk from the inhalation of vapor are described in following sections.

Data Sources and Model Inputs for Estimating Volatile Emissions

The emissions model requires the soil/water partition coefficient as one input. This partition coefficient is, in turn, based on the fraction of organic carbon in the soil. The higher the f_c value, the lower the emissions, since more of the contaminant will partition to soil. For land application ~~sites where sludge~~ is soil-incorporated, it is assumed that the fraction of organic carbon in the sludge-soil mixture is approximately equal to the fraction of organic carbon in the soil alone. A reasonable best estimate for f_c for soils is 1%, with a range from 0.1% to 4%. This range of values is used in the typical exposure analysis. In the MEI analysis, the "best" estimate of MEI exposure is calculated assuming an f_c value of 1%, while the "high risk" MEI exposure estimates is calculated using an f_c value of 0.1%. For those land application sites where top-dressing is practiced, the average value of f_c for sludge is used. NCASI (1984) reports that the organic carbon content of sludge ranges from 14% to 40%. The typical exposure analysis uses 25% for a best estimate of f_c for sludge; the "low risk" analysis uses a value of 40%, while the high risk analysis uses a value of 14%. Values of 25% and 14% are used in the calculation of the "best" and "high risk" MEI exposure estimates, respectively.

Data Sources and Model Inputs for Estimating Exposure to TCDD and TCDF Vapor

The data inputs and model sources for the vapor exposure estimate are the same as those described in section 2.4.4., with two exceptions. First, 100 percent of vapor emissions are assumed to be respired. Second, all of the vapor is absorbed through the lung; none is absorbed through the GI tract.

2.4.6 Estimates of Exposure and Risks from Ingestion of Drinking Water from Ground Water Sources

Land application of sludge is not expected to present significant risks to human health through contamination of ground water. As explained in Section 2.1, conservative, "high risk" estimates of ground water contamination from sludge in industrial landfills yielded risk estimates on the order of 10^{-6} for a "most exposed individual"; "best estimate" assumptions yielded lower risk estimates. Consideration of some major differences between landfilling and land application /of pulp and paper sludge suggests that risks of groundwater contamination and human health risks from land application should be lower than those estimated for landfills.

Land application and landfill sites differ in at least five important respects. First, land application sites may be larger than landfills. Second, local geo-hydrological or weather conditions may differ between landfill and land application sites. Third, sludge may be placed in landfills to a significant depth below ground level; land-applied sludge is generally applied to the ground surface, or incorporated into a relatively shallow surface soil layer. Fourth, the quantities of sludge applied to a hectare of treated land tend to be much lower than the quantities deposited in a hectare of landfill. Finally, the maximum concentration of TCDF reported in the 104-Mill Study for land-applied sludge is lower than the maximum reported for sludge placed in landfills. These differences, and their implications for human health risks estimates, will now be examined.

Land application sites can be larger than sludge landfills. A known forest application site in Wisconsin, for example, reportedly covers approximately 1,000 hectares of land (Wisconsin environmental department). Landfills are generally assumed to be much smaller; Section 2.1 of this analysis assumes that they generally cover less than about 25 hectares. If the land application site is significantly larger than a sludge landfill, then the area of underlying aquifer receiving recharge from the site may be larger as well. Section 2.1.2 assumed that the vertical migration of contaminants through a sludge landfill and underlying soil layers is not affected by the area of a site. Once contaminants enter the ground water, however, the extent of their dilution in transport to a nearby drinking water well is affected by the area of the site.

Repeated execution of the AT123D model (discussed in Section 2.1.2) shows that estimated concentrations at the receptor well increase approximately four-fold as the site size is increased by a factor of 100, and all other inputs for the model runs (except site size) are held constant. A landfill with characteristics described in Section 2.1.2, but with a size equivalent to the area covered by the Wisconsin land application site would therefore be expected to result in health risks no more than four times higher than those estimated in Section 2.1.2.

The second difference between the two sludge management practices is that land application sites may be located in areas with different topography, geology, and meteorology than those areas in which pulp and paper sludge landfills are sited. If these local conditions are more conducive to ground water contamination than those assumed for landfills, then the risks associated with land application could conceivably be higher than those estimated for landfills. For example, strip-mined land receiving sludge applications may include fractured rock layers that are especially vulnerable to the migration of sludge contaminants to underlying ground water. The "high risk" scenario considered in Section 2.1.2, however, assumed a zero distance between the bottom of the landfill and the water table, assumed that leachate concentrations are limited only by the concentration of contaminants in the sludge and their estimated partition coefficients, and used reasonable worst case parameter values for most of the environmental transport calculations. It is unlikely that an aquifer located beneath a land application site would be significantly more vulnerable to contamination than an aquifer of characteristics assumed for the "high risk" scenario in Section 2.1.2.

A third difference between the two practices is that for most land application sites, sludge is applied to the soil surface, or incorporated into a soil layer of only 10 to 20 centimeters in thickness. Landfills, by contrast, can extend several meters beneath the soil surface. Section 2.1.2 examined a "high risk" landfill scenario that included a sludge layer that extended six meters downward to the water table. The vertical distance between the sludge layer and the water table is likely to be greater for land application sites than the zero distance assumed for a "high risk" landfill scenario. TCDD and TCDF concentrations in water that has percolated downward through an initially clean soil layer are therefore likely to be lower than those predicted for the "high risk" landfill scenario. Even if the sludge could be incorporated into the entire soil layer above the water table, expected contaminant concentrations in the soil-sludge mixture (and hence maximum expected concentrations in ground water) would be significantly lower than those modeled in Section 2.1.2.

A fourth difference between land application and landfilling of sludge is that the concentrations of TCDF in land-applied sludge tend to be lower than those in sludge that is landfilled. Maximum reported concentrations in landfilled sludge are 520 ppt for TCDD and 6,740 ppt for TCDF. The highest reported concentrations for land-applied sludge are 681 ppt and 1,300 ppt for TCDD and TCDF, respectively. Although maximum TCDD concentrations are comparable for the two practices, maximum TCDF concentration in land-applied sludge is about five times lower than that in landfilled sludge. Since TCDF dominates the risks estimated in Section 2.1.2, one would expect that the lower TCDF concentrations in land-applied sludge would result in lower risks from this sludge management practice.

A fifth difference is that the quantity of sludge applied to a hectare of treated land is generally lower than the quantity deposited in a hectare of landfill. If so, and if the concentrations of TCDD and TCDF in land-applied sludge are lower than the concentrations in landfilled sludge, then it would follow that loadings of these contaminants to ground water beneath a land application site would probably be lower than those beneath a landfill, all else equal. Based on estimated cumulative application rates and sludge quality for land application sites (described by Table 2.4.A), the average loading of TCDD per hectare of treated land will range from less than 0.01 percent (Maine) to about 40 percent (Mississippi) of that assumed for the "high risk" landfill scenario. The corresponding range for TCDF is from less than 0.01 percent (Pennsylvania and Maryland) to 1.3 percent (Georgia). Since almost all of the human health risk associated with ground water contamination from TCDD and TCDF is caused by TCDF, these loadings suggest that estimated ground water contamination from land application is likely to be lower than that from landfills, if all conditions other than contaminant loading are held constant.

Although a comparison of contaminant loading per hectare for landfills and land application sites would suggest lower risks through ground water than those estimated for landfills, the "high risk" methodology used for estimating landfill risks actually ignores sludge quantity when estimating ground water contaminations. Instead, it predicts maximum water concentrations based solely on contaminant concentrations in the sludge, organic carbon content, and equilibrium partition coefficients for TCDD and TCDF. Still, the theoretical basis for that methodology would suggest lower risk estimates from land application sites for two reasons. First, if sludge concentrations of

TCDF are lower for land application sites then for landfills, then the maximum expected concentration of dissolved contaminant in leachate beneath a land application site would be correspondingly lower than that expected beneath a landfill. Second, if sludge is soil incorporated (as in Mississippi, Ohio, Pennsylvania and Wisconsin), then contaminant concentrations in the mixed sludge-soil layer will be significantly lower than the concentrations reported for pure sludge. It follows that maximum concentrations of dissolved contaminant in that layer will also be lower. For land application sites in which sludge is not soil incorporated, the maximum concentrations predicted on the basis of sludge quality alone are unlikely to apply to water that has percolated through an initially uncontaminated soil layer beneath a land application site.

The remainder of this section will argue that risks to human health through ground water contamination beneath land application sites are lower than those estimated for the "high risk" scenario examined in Section 2.1.2, and are therefore too low to justify more detailed evaluation. Each of the seven states in which land-application is known to be practiced will be considered individually.

In Georgia, sludge is applied to forest land at a relatively high rate of about 2,000 dry metric tons per hectare. Since TCDD and TCDF concentrations in the sludge are significantly lower than those assumed for the "high risk" landfill scenario, and since application areas are assumed to be comparable to those assumed for landfills, there is no reason to believe that risks from these sites could be as high as those estimated in Section 2.1.2. In Maine, sludge is applied to forest land at relatively low rates of application. If, as a worst case, the entire 450 hectares of treated land were modeled as a single site, then ground water contamination at a well 200 meters from the site would be expected to be about three times as high as those estimated for a similar site of only about 25 hectares. But the concentrations of TCDD and TCDF in the Maine sludge are more than one and two orders of magnitude lower, respectively, than those evaluated in Section 2.1.2. Hence risks from this site should be significantly lower than those estimated for the "high risk" landfill scenario.

In Maryland, sludge is applied to strip mined land, sometimes at depths as great as 25 meters for filling open cuts. This depth exceeds the maximum of six meters assumed for landfills, and might conceivably result in direct contact between sludge and ground water. It should be noted, however, that the "high risk" landfill scenario discussed in Section 2.1.2 assumes that leachate from the landfill enters directly into the aquifer (without passing through a thickness of intervening soil), and that contaminant concentrations in that leachate are limited only by sludge concentrations and partition coefficients for TCDD and TCDF. Although sludge may be applied at great depths in localized areas maximum predicted leachate concentrations should not exceed those estimated on the basis of sludge concentrations and partition coefficients, as explained in Section 2.1.2. Since the concentration of

TCDD in the Maryland sludge is more than an order of magnitude lower than that assumed for landfills, and the concentration of TCDF is lower by a factor of more than eighty, risks of ground water contamination from the Maryland sites should be significantly lower than risk estimates derived for landfills. Sludge is also applied to strip-mined land in Ohio. As in Maryland, the relatively low concentrations of TCDD and TCDF in the land-applied sludge more than offset possible increases in risk associated with a large application area.

In Mississippi, sludge is applied yearly at moderate rates to a relatively large total area of agricultural land. The Mississippi plant reported a zero concentration of TCDF in its sludge, however, and since TCDF tends to dominate risk estimates through the ground-water pathway, estimated risks for these sites will be low. In addition, sludge is soil incorporated at this site, reducing sludge concentrations by a factor of forty or more. Maximum dissolved concentrations in water percolating through the treated soil should therefore be significantly lower than those estimated for landfill leachate. In Pennsylvania, sludge is applied yearly to agricultural land at relatively low application rates. Incorporation of the sludge into soil probably reduces TCDD and TCDF concentrations in the sludge-soil mixture by a factor of 200 or more, resulting in relatively low soil concentrations, and hence lower risks than the estimates derived for landfills.

Finally, sludge is applied to a relatively large area of forest land in Wisconsin (about 1000 hectares). The sludge is applied only once to each treated area, at a relatively low rate of about 40 metric tons per hectare. Since the large application area is expected to increase risks by no more than a factor of four (relative to the 25 hectare site considered for landfills), since the sludge concentrations reported for the Wisconsin plant are roughly five and four times lower than maximum concentrations of TCDD and TCDF respectively in landfilled sludge, risks from treated areas in Wisconsin can be expected to be lower than the estimates derived for landfills.

For these reasons, the risks estimated for the "high risk" landfill scenario provide an adequate upper bound of possible risks through the ground water pathway of exposure for land application of sludge. In fact, there are several reasons to believe that ground water risks from land application would be significantly lower than those estimates for landfills. Since health risks from landfills were estimated to be 10^{-6} or less for the ground water pathway of exposure, risks through ground water contamination from land application do not appear to justify more detailed evaluation.

2.4.7 Estimates for Exposure and Risk from Ingestion of Drinking Water from Surface Water Sources

Where pulp and paper sludge is applied to land, particles of sludge or soil from the surface can be transported by erosion to nearby lakes or streams. If humans consume water from these lakes or streams, they may be exposed to TCDD and TCDF from the land applied sludge. This Section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health.

The methodology to estimate exposure consists of three general steps. First, based on sludge concentrations of TCDD and TCDF, local topography, land use and other factors, it estimates contaminant concentrations in sediments and surface water. Second, it uses these estimated concentrations, assumptions about individual ingestion of drinking water, and assumptions about the bioavailability and the cancer slope factors of TCDD and TCDF, to estimate individual health risks for humans potentially exposed. Third, it combines these results with estimates of the size of exposed populations to derive estimates of total human health risks to the U.S. population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Details of the methods used for these calculations are presented in Appendix B. In general, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the SMA. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the SMA surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases, based on the assumption of equilibrium partitioning between the two phases.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Drinking Water from Surface Water Sources

Water concentrations are multiplied by human consumption of water and a bioavailability factor to yield the estimated human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$\text{Dose}_w = \frac{C_w\, Q_w\, BA_w}{BW}$$

where:

C_w = Concentration of contaminant in water (mg/liter),

BA_w = Bioavailability of TCDD or TCDF from ingested water (unitless),

BW = Human body weight (assumed to be 70 kg),

Q_w = Individual's consumption of water (liters/day),

$Dose_w$ = Dose of contaminant from consumption of water (mg/kg/day).

Methods for Estimating the Size of Exposed Populations

The size of the population exposed to contaminated water is estimated by first multiplying the area of the drainage basin above each SMA drainage point by the estimated population density of that area. This estimated population is then multiplied by the fraction of the population that takes its drinking water from surface supplies:

$$PE_w = A_B \; PD \; PSW$$

where:

PE_w = Population exposed to contaminated water;
A_B = Area of the drainage basin (ha);
PD = Population density for region of land application site (persons/ha);
PSW = Percent of population served by surface water.

Data Sources and Model Inputs

The values used for each model input are summarized in Table 2.4.M and Table 2.4.N for a typical and the most exposed individual, respectively. The following sections describe each input and document the data sources used to obtain values for each model input.

Data Sources and Model Inputs for Soil Concentration

Eight mills in seven states are currently land applying sludge and are considered in the surface water pathway. Risk estimates are calculated separately for each group of land application sites associated with a particular state. State-specific data includes estimates of: sludge concentrations; soil incorporation depth; area of the application sites; type of application (e.g., forest, agriculture, mine reclamation); and distance to the nearest stream.

Table 2.4.M. Assumptions and Parameter Values for a Typical Individual - Land Application: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
SMA Vegetative Cover	90%	90%	None		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
"C" ratio				See text.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
Agriculture:	1	4	6		
Forest:	1	1	1		
Mine reclamation:	1	1	1		
"P" ratio				Low risk assumes farms use contour strip cropping; best estimate assumes contouring; high assumes no support practices.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
Agriculture:	0.6	0.75	1		
Forest:	1	1	1		
Mine reclamation:	1	1	1		
Drainage Area (ha)	129,500	1,295,000	1,295,000	"Best" and "high" scenarios assume the sites drain into a major waterway. The "low risk" scenario assumes the sites drain into a smaller tributary.	
Percent Organic Carbon in Soil	0.04	0.01	0.001		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2	2		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)

Table 2.4.M. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100	100		
Fish to sediment ratio					
-- Dioxin	.0967	.0967	10		Low and best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
-- Furan	.1538	.1538	10		
Fish consumption (grams/day)	6.5	6.5	16	Includes fresh water and estuarine fish and shellfish.	Low and Best: U.S. EPA "Estimating Exposure 2,3,7,8 TCDD" (1988), OHEA, Exposure Assessment Group (Draft) High: U.S. EPA "Risk Assessment for Dioxin Contamination Midland," Michigan; April, 1988
Percent of fish consumed by the exposed population that is contaminated	100	100	100		
Human Absorption:					
Water	100	100	100		
Fish:	85	90	95		U.S. EPA memo from Dioxins in Paper Work Group. "Bio-availability of Dioxins in Paper Products," 6/23/89

Table 2.4.M. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5	0.5		U.S. EPA memo, "Bio-concentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	173	173	173		U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	46	46	46	Average for relevant states.	USGS National Water Survey
Sportfisher fish consumption (grams/day)	N.C.	48	48		Humphrey (1983) in U.S. EPA (1988)
Percent of population consuming fish at Sportfisher level	N.C.	3.7	3.7		US Department of Agriculture, "National Food Consumption Survey, 1977-1978"

Table 2.4.M. (cont.) Assumptions and Parameter Values for a Typical Individual - Land Application: Surface Water Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Distance to stream (meters)					
Georgia	3,218	3,218	801		Low and best estimates use the state of Maryland's estimated distance to surface water of approximately 2 miles (3218 meters). High estimates use permit limits when they exist (GA, OH, & PA), an estimated distance when given by the state (MD), or 1 meter in the absence of permit limits or state estimates (ME, MS, WI).
Maine	3,218	3,218	1		
Maryland	3,218	3,218	3,218		
Mississippi	3,218	3,218	1		
Ohio	3,218	3,218	46		
Pennsylvania	3,218	3,218	30		
Wisconsin	3,218	3,218	1		

Notes: N.C. = Not calculated.

Table 2.4.N. Assumptions and Parameter Values for the Most Exposed Individual - Land Application: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
SMA Vegetative Cover	None	None		U.S. EPA (1988), "Estimating Exposure to 2, 3, 7, 8-TCDD," OHEA, Exposure Assessment Group (Draft)
"C" ratio			See text.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
Agriculture:	6	6		
Forest:	1	1		
Mine reclamation:	1	1		
"P" ratio				"Predicting Rainfall Erosion Losses," USDA Handbook #537
Agriculture:	1	1		
Forest:	1	1		
Mine reclamation:	1	1		
Drainage Area (ha)	4047	4047	Assumes that the SMA drains into a relatively small stream.	U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Percent Organic Carbon in Sediment	0.01	0.001		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8 TCDD", OHEA Exposure Assessment Group (Draft)

Table 2.4.N. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Land Application: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Percent of water consumed that is contaminated	100	100		
Fish to sediment ratio (whole body)				Best: U.S. EPA memo: "Bioconcentration Factors For 2,3,7,8-CDD and -CDF," 8,8,89; High from U.S. EPA, (1988) "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
-- Dioxin	.0967	10		
-- Furan	.1538	10		
Fish consumption (grams/day)	100	100		Humphrey (1976) in EPA (1988), "Risk Assessment for Dioxin Contamination. Midland, Michigan."
Percent of fish consumed that is contaminated	100	100		
Human Absorption:				
Water:	100	100		U.S. EPA memo from Dioxins in Paper Work Group. "Bio-availability of Dioxins in Paper Products," 6/23/89
Fish:	95	95		
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA (1989) memo, "Bio-concentration Factors for 2,3,7,8-TCDD and TCDF," August.

Table 2.4.N. (cont.) Assumptions and Parameter Values for the Most Exposed Individual - Land Application: Surface Water Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Distance to stream (meters)				
Georgia	801	801		
Maine	1	1		
Maryland	3,218	3,218		
Mississippi	1	1		Estimates use permit limits when they exist (GA, OH, & PA), an estimated distance when given by the state (MD), or 1 meter in the absence of permit limits or state estimates (ME, MS, WI).
Ohio	46	46		
Pennsylvania	30	30		
Wisconsin	1	1		

The method for calculating soil concentration from sludge concentration is discussed in Appendix A. The application rates and soil incorporation depths for the sites receiving the sludge of the seven land applying mills are displayed in Table 2.4.A along with soil and sludge concentrations. Sludge concentrations are taken from the U.S. EPA 104-Mill study. The remaining data were obtained from discussions with state officials familiar with the site land application practices except for the following data. Application rates for one mine site and one forest site were obtained from Keenan (1989) and Martin et al (1987), respectively. Sludge applied to forest land, though surface-applied, is assumed to be soil-incorporated to a level of 2.5 centimeters to reflect the accumulation of duff and the effects of activity on the forest floor over the 70 year period of analysis.

Data Sources and Model Inputs for Sediment Concentration

As explained in Appendix B, the parameters necessary to calculate sediment concentration (before partitioning) from soil concentration are: site area, site sediment delivery ratio, drainage area, drainage area sediment delivery ratio, and the Universal Soil Loss Equation parameters.

The soil concentrations are discussed above. SMA areas are listed in Table 2.4.A and Table 2.4.B for each of the states. These areas were obtained from discussions with state officials familiar with the SMA characteristics. In some instances, the area was calculated by dividing total land applied sludge quantities by the application rate per unit area. Maine's SMA area was available only as a range. The midpoint is taken as the "best estimate". At least 25 hectares are estimated to be receiving sludge in the State of Maryland, with an upper limit of 40 hectares. The "best estimate" assumes that 25 hectares are sludge-amended.

The calculation for the SMA sediment delivery ratio, as shown above, depends on the overland distance between the SMA and the water body. In the majority of cases, this information was unavailable. The State of Maryland, however, gave this figure as approximately 2 miles (or 3218 meters). This distance was used as the "best estimate" of typical risk for all states. Three states had permit requirements for the minimum distance between an SMA and a waterway. When available, these limits were used for the "high risk" estimate for typical individuals and the "best" and "high" risk MEI estimates. Where no permit limits exist and actual distances are not known, the "high risk" estimate for typical individuals and "best" and "high" risk MEI estimates assume that the SMA is located 1 meter from the stream. The values used to estimate the distance between the SMA and a stream are presented in Table 2.4.M. for typical risk and 2.4.N for MEI risk.

The watershed sediment delivery ratio is dependant on the area of the watershed. The "best estimate" and "high risk" typical individual estimate assume the water body receiving SMA runoff is a major stream with a watershed area of 5,000 square miles. This estimate is based on U.S. EPA Geographic Exposure Modeling System (GEMS) estimates of drainage area for major streams (U.S. EPA, 1989c). The "low risk" typical individual estimate assumes that the receiving water body is a smaller tributary with a watershed area of 500 square miles. The watershed in the MEI scenarios is assumed to be 10,000 acres (approximately 40 square miles). This area corresponds to a relatively small stream (U.S. EPA 1988a).

The cover management and support practice variables from the USLE equation are determined as a ratio of SMA to watershed. This analysis assumes that forest and mine reclamation SMAs will be surrounded by land with similar cover and will not have any support practices. The "C" and "P" ratios are therefore 1:1. However, agricultural land may differ in its cover from the surrounding land and practices may be in place to slow the runoff water and thus reduce the amount of soil it can carry. "C" values for cropland range from approximately 1% to 85%, averaging approximately 40% (Science and Education Administration, 1978). In other words, the approximate average soil loss from crop land under specified conditions is 40% of the corresponding loss from clean-tilled, continuous fallow . "C" values on permanent pasture, range, and idle land range from approximately 0.3% to 45%, with an average of approximately 10%. "C" values on undisturbed woodland range from 0.01% to 9% with an average of approximately 0.3%. On woodland that has been grazed, burned, harvested, or re-established after harvest, the approximate average "C" value is 7% (Science and Education Administration, 1978).

In this analysis, the "low risk" typical individual estimate assumes that the watershed area for streams receiving agricultural runoff is largely agricultural land; the "best estimate" for typical individuals assumes that the watershed area is largely pasture land; and the "high risk" typical individual estimate assumes that the watershed is largely woodland that has been grazed, burned, harvested, or re-established after harvest. The MEI risk estimates assume that the watershed area is largely disturbed woodland. The resultant "C" ratios are displayed in Table 2.4.M. for typical individuals and 2.4.N. for the MEI.

The "P" factor in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up-and-down-slope culture. Tillage and planting on the contour result in a "P" factor of 0.75. Stripcropping, a practice in which contoured strips of sod are alternated with equal-width strips of row crops or small grain, results in a "P" factor of 0.6 (Science and Education Administration, 1978). This analysis assumes stripcropping for the "low risk" typical individual scenario, contouring for the typical individual "best estimate", and no control practices for the "high risk" typical individual scenario. The MEI analyses assume that no control practices are in place.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the partition coefficient between water and organic carbon, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the partition coefficient between sediment and water. The Koc value for TCDD used in this analysis is 1×10^7 (Jackson, 1985 in EPA, 1987c). The Koc value for TCDF is 3.5×10^6 (CHEMEST procedure in GEMS, U.S. EPA, 1989c). The organic carbon content is assumed to be 0.04 in the "low risk" typical individual estimate, 0.01 in the typical individual and MEI "best estimate", and 0.001 in the "high risk" typical individual and MEI estimate (U.S. EPA, 1988a).

Data Sources and Model Inputs for Estimating Human Dose

Individual water consumption is assumed to be 2 liters per day (U.S. EPA, 1988a). The bioavailability of ingested water is assumed to be 100 percent (FDA, 1989).

Data Sources and Model Inputs for Estimating the Size of the Exposed Population

The size of the exposed population is estimated by multiplying the watershed area of the contaminated stream by the population density of the regions in which the SMA's are located. To accurately estimate the size of the population exposed on a site-specific basis, it is necessary to know the stream into which the SMA runoff drains, the dilution and dispersion pattern of the contaminant, and the patterns of water withdrawal from the water body. In the absence of this site-specific information, the size of the exposed population is estimated as follows.

The typical individual "best estimate" assumes that the receiving stream for each SMA is a major stream with a 5,000 square mile watershed area. It is further assumed that the size of the exposed population increases with stream size, and that stream size increases with drainage area i.e., the larger the drainage area, the more people are likely to use the stream for a drinking water supply. To capture this relationship, the size of the exposed population is approximated by the number of persons expected to live in the area of the drainage basin containing each landfill. The area of each basin is multiplied by the average population density in the regions through which the waterway flows. Population density is determined by averaging populations for the regions of the United States where sludge is land applied and dividing by the area for these regions. Regional populations were considered rather than state populations because the contaminated waterways are not limited by state boundaries. The average population density for regions where land application sites are located is 173 people per square mile (U.S. Department of Commerce, 1987).

Only a portion of this population will rely on surface water for their drinking water. The estimated population exposed is therefore reduced by multiplying by the average percentage of population served by surface water. Forty-six percent of the population is assumed to be served by surface water (U.S. Geological Survey, 1985).

This analysis assumes that the entire exposed population ingests water at concentrations estimated at the "point" of entry of the SMA runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles, this assumption is conservative. In reality, dilution and dispersion of the contaminant will probably have occurred before much of the population is exposed. However, in the absence of additional site-specific information, it was not possible to calculate exposure more exactly.

One test of the reasonableness of the analysis' assumption about the size of the exposed population is to compare the amount of drinking water assumed to be withdrawn from the contaminated stream with the stream's flow rate. If the stream can not supply the quantity of water that the analysis assumes is ingested then the assumptions must be reexamined.

The "best" risk estimate for the population assumes that a water body with a drainage area of 5000 square miles is contaminated. A water body with this drainage area would be a relatively major stream, receiving runoff from an area approximately 70 by 70 miles. Several streams located near paper mills have a drainage area of a few thousand square miles. For example, Raccoon Creek at Granville, OH has a drainage area of 8,270 square miles (GAGE data base, U.S. EPA).

The U.S. Geological Survey (USGS) has studied the relationship between a stream's drainage area and mean annual flow rate using regression analysis. On a national scale, USGS found drainage area to be the most significant variable influencing flow rate; other variables, particularly average annual precipitation, were also sometimes significant (personal communication, USGS). Since annual precipitation varies substantially throughout the United States, drainage area alone is not a precise predictor of stream flow. However, the general relationship between drainage area and stream flow can be estimated for regions of the country.

For regions east of the Mississippi, the range of stream flows associated with a drainage area can be approximated from the following equations (personal communication, USGS).

Low Estimate

MAF = DRA

High Estimate

MAF = 1.5 DRA

where:

DRA = Drainage area (square miles), and

MAF = Mean annual flow rate (cubic feet per second or cfs).

Regions west of the Mississippi will exhibit greater variability in stream flows with relationship to drainage area, with extremely arid areas approaching zero cubic feet per second per square mile of drainage area. However, moderately arid regions are likely to exhibit a relationship between stream flow and drainage area that can be approximately represented by the following equation:

MAF = 0.5 DRA

Using these formulas to predict mean annual flow rates for a stream with a 5,000 square mile drainage area yields 5,000 to 7,500 cfs in relatively humid (generally eastern) states and about 2,500 cfs in relatively arid (generally western) states. Converted to liters per year, the mean flow rates are 4.5×10^{12} to 6.7×10^{12} liters/year for humid states. Arid states have a mean annual stream flow rate of approximately 2.2×10^{12} liters per year associated with a stream from a 5,000 square mile drainage area.

The flow rate for a stream with a 5,000 square mile drainage area can be compared with the quantity of drinking water assumed to be withdrawn from the stream to evaluate the feasibility of assumptions about the size of the exposed population. To estimate drinking water withdrawals, the exposed population is multiplied by the quantity of water consumed per person. The analysis assumes that a person consumes 2 liters of water per day. The population exposed varies between different types of sludge management, based on the population density of the regions of the country in which the facilities are located. The exposed population also varies according to the percent of the population that receives its drinking water from surface water. For surface impoundments, the population exposed to contaminated water is estimated to be 80 persons per square mile of drainage area.

A comparison of water withdrawals and stream flows for land application sites suggests that a relatively large population might use the affected water. The water withdrawals will be from a stream with a relatively high stream flow:drainage area ratio, since land application sites are located in the eastern United States. Water withdrawal for drinking is calculated by multiplying a 5,000 square mile drainage area by 80 exposed people per square mile. This yields an exposed population of 400,000 people. Total surface water withdrawal for drinking, at 2 liters per person per day, is 2.9 x 10^8 liters/year. Comparing the water withdrawals to the stream flow shows that between 0.004 and 0.006 percent of the stream flow is withdrawn for human consumption.

It is likely that the population receiving its drinking water from contaminated surface water will receive the remainder of water for domestic uses from this same source. Therefore, it is also informative to compare total water withdrawn for domestic use with the stream flow. Average domestic water use is 78 gallons, or 295 liters, per person per day (USGS, 1985). This quantity multiplied by a population of 400,000 people equals annual domestic use of 4.3 x 10^{10} liters per year. Total domestic use as a percentage of stream flow is between 0.6 and 0.9 percent.

In evaluating the plausibility of this result, one should note that 77% of water used domestically is return flow (USGS, 1985). This means that the water reaches a ground- or surface-water source after release from the point of use and thus becomes available for further use. The above discussion suggests that the assumptions in this analysis about the size of populations exposed to surface water area are plausible.

2.4.8 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Where pulp and paper sludge is land applied, particles of sludge or soil from the SMA surface can be transported by erosion to nearby lakes or streams. If the sludge contains TCDD or TCDF, then those particles can carry these contaminants to the surface water bodies. Fish living in the lakes or streams can take up sludge contaminants into their tissue; if humans then consume those fish, they can be exposed to TCDD and TCDF.

This Section discusses methods used to estimate the extent of this potential exposure, and its associated risks to human health. The methodology is quite similar to that discussed in Section 2.4.7, in that both methodologies begin by estimating sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from land application sites. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 2.4.7, and uses fish to sediment bioconcentration factors and estimates of human consumption of fish to calculate contaminant doses to humans. The last step in the methodology involves estimating the size of the exposed population, combining these results with estimates of individual dose and health risk to derive total health risks to the entire exposed population. Each of these steps will now be discussed.

Methods for Estimating TCDD and TCDF Concentrations in Surface Water

Methods used for these calculations are described in detail in Appendix B. In summary, the methods are adapted from U.S. EPA (1985a), and use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake or stream's sediment that originates from the SMA. By multiplying this fraction by the original concentration of TCDD and TCDF in soil particles from the land application site, the methodology derives estimates of the concentration of contaminants in the sediment. These sediment concentrations can then be used to estimate contaminant concentrations in the tissues of fish.

Methods for Estimating the Concentration of TCDD and TCDF in Fish Tissues, as a Function of Sediment Concentrations

Methods for estimating contaminant concentrations in fish are discussed in detail in Appendix B. Based on the assumption that sediment concentrations are the best predictor of fish concentrations of hydrophobic compounds like TCDD and TCDF, the methodology uses empirical fish to sediment bioconcentration factors to estimate concentrations of contaminant in freshwater fish as a function of concentrations in stream or lake sediment. As explained in Appendix B, the concentrations of TCDD and TCDF in the muscle tissues of fish (consumed by humans) are considered to be fifty percent lower than the whole body concentrations of these contaminants.

Methods for Estimating Human Dose of TCDD and TCDF from Ingestion of Fish

Estimated contaminant concentrations in fish tissue are multiplied by an estimated amount of fish consumed daily and a bioavailability factor to yield human dose of TCDD or TCDF. This estimated dose is divided by body weight to derive an estimated dose of contaminant per unit of body weight per day:

$$\mathrm{Dose}_F = \frac{C_F\, Q_F\, BA_F}{BW}$$

where:

BA_F = Bioavailability of TCDD or TCDF from fish (unitless)

BW = Human body weight (assumed to be 70 kg)

C_F = Concentration of contaminant in fish tissue (mg/g)

Q_F = Individual's daily fish consumption (g/day)

$Dose_F$ = Dose of contaminant from consumption of fish (mg/kg/day)

Methods for Estimating the Size of Populations Exposed to TCDD and TCDF through Ingestion of Fish

The size of the population exposed to fish containing TCDD and TCDF is estimated by multiplying the area of the drainage basin containing each land application site by an estimated population density of the regions containing the sites.

$$PE_F = A_B \, PD$$

where:

PE_F = Population exposed to contaminated fish

A_B = Area of the drainage basin (ha)

PD = Population density for region of land application site (persons/ha)

Data Sources and Model Inputs for Estimating Human Dose

A contaminant dose from ingestion of contaminated fish is estimated for three populations: typical individuals, an MEI, and sport fishers. As an input to the dose calculation, consumption of freshwater and estuarine fin fish and shellfish is estimated for these three populations. Numerous studies report quantities of fish consumed by humans but most include marine fish. U.S. EPA has cited 6.5 grams/day as the average freshwater fish consumption (U.S. EPA, 1980, in U.S. EPA 1988b). The Food and Drug Administration (FDA) has estimated 16 grams per day as the upper 90th percentile ingestion rate of freshwater fish in the Great Lakes area (U.S. EPA, 1988c). This analysis assumes fish consumption of 6.5 grams per day for a typical individual in the "low risk" scenario and "best estimate" and a consumption rate of 16 grams per day for the typical individual "high risk" exposure estimate.

Since these overall averages include a large proportion of individuals who eat no freshwater fish at all, particular populations may consume larger quantities. In particular, sport fishers are likely to consume fish at a higher rate than a typical individual. The "best estimate" and "high risk" sport fisher scenarios incorporate the assumptions used in the population "best estimate" and "high risk" scenarios, respectively except they use different rates of fish consumption and a smaller exposed population to reflect the typical behavior of sport fishers. This analysis assumes sport fishers consume 48 grams of fish per day in both the "best estimate" and the "high risk" scenarios. This is the median consumption rate for sport fishers in Michigan reported by Humphrey (1983). The MEI analysis uses the 90th percentile consumption rates of active sport fishers, 100 grams per day, to represent MEI consumption rates in the "best" and "high" risk estimates (Humphrey, 1976).

Bioavailability rates for the contaminants consumed in fish are taken from U.S. EPA (1989c). TCDD and TCDF are assumed to be 85, 90, and 95 percent bioavailable for "low", "best", and "high" calculations, respectively. Contaminants consumed with fish are assumed to be 95 percent bioavailable in both the "best" and "high" MEI risk estimates.

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

This analysis assumes that all fish are consumed regionally. An alternative would be to assume that the fish are distributed nationally. In that case, the percent of the freshwater fish each person consumes from the contaminated stream might be calculated by calculating the ratio of the drainage area of the contaminated stream to the drainage area of the entire United States. This percentage could then be used as the percent of contaminated freshwater fish consumed by the entire U.S. population. Instead, the current methodology uses drainage area to determine the proportion of U.S. citizens who are exposed to the contaminated water and fish. This population is then assumed to consume 100% of their freshwater fish from the contaminated stream. These two methods will yield similar estimates of population risk since the analysis assumes a linear dose-response relationship.

As previously discussed, sizes of exposed populations are estimated by multiplying estimated watershed area by estimated population density. To accurately estimate site-specific populations exposed it is necessary to know the stream into which the SMA runoff drains, the downstream uses of the surface water (e.g., fishing, drinking), and the distribution of the fish that are caught. In the absence of this site-specific information, the size of the exposed population is estimated as follows.

It is assumed that the size of the population exposed will be positively correlated with stream size and that stream size will be positively correlated with drainage area; the larger the drainage area, the more people are likely to receive their drinking water supply from the stream. To quantify this relationship, population exposed is modeled as a function of drainage area. Each unit area of the watershed is multiplied by the average population density for the regions through which the waterways flow to yield population exposed. For land application sites, the population density is 173 people per square mile.

In the "best estimate" and the "high risk" scenarios for typical individuals, it is assumed that the receiving stream for each SMA is a major stream with a 5,000 square mile watershed area. In the "low risk" estimate for typical individuals, the drainage area is assumed to be one-tenth of this size, or 500 square miles. The drainage area in both MEI scenarios is assumed to be about 40 square miles. This corresponds to a relatively small stream (U.S. EPA, 1988a).

To calculate the sportfisher population exposed to contaminated fish, the total population exposed is first calculated as described above. The percentage of U.S. non-metropolitan households consuming "home produced" fish and poultry is estimated to be 7.1% (U.S. Department of Agriculture 1978). The percentage of these households consuming "home produced" poultry is estimated at 3.4% (U.S. Department of Agriculture 1978). If the populations home-producing poultry and fish do not overlap then 3.7% of the population home-produces fish. To estimate the population consuming fish at the median sportfisher level of 48 grams per day, the total population exposed is multiplied by 3.7%. This calculation assumes that the family of a sportfisher consumes fish at the same rate as a sportfisher.

This analysis assumes that the entire exposed population ingests fish at concentrations appropriate for the "point" of entry of the SMA runoff into the stream. Since the population exposed will inhabit an area of approximately 70 by 70 miles in the "best" and "high" estimates, this assumption is conservative, and will tend to overstate exposure and risk. In reality, dilution and dispersion of the contaminant would have occurred before much of the population was exposed.

2.4.9 Summary of Results

Human exposures associated with the land application of sludge are summarized in Table 2.4.O. The risks resulting from these exposures are summarized in Table 2.4.P. Typical risks to individuals are low through all pathways analyzed for this disposal/use practice. Highest typical individual risks are estimated for persons living on the land application site who are exposed through direct ingestion vapor inhalation, and dermal contact with contaminated soil. The highest typical individual risk is associated with the vapor inhalation pathway: the incremental lifetime risk from this pathway is estimated to be 7 x 10^{-6}. However, because the size of the population exposed through this pathway is small, the total annual cancer risk resulting from this exposure is estimated to be only 4 x 10^{-6} cases per year.

Lowest typical individual risks from the land application of sludge are for individuals in the general population that consume produce, meat or dairy products grown in sludge-amended land The typical incremental lifetime risk from dietary exposure is estimated to be 2 x 10^{-8}. Although the typical individual risk is low, the populations exposed through these pathways are large. The food from sludge-amended land is assumed to be nationally distributed, while contaminated surface water

Table 2.4.0. Best Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
ermal exposure from contact with soil contaminated by land application of sludge:	6×10^{-10}	(>99)	1×10^{-11}	(>99)
xposure from direct ingestion of soil contaminated by land application of sludge:	2×10^{-9}	(>99)	1×10^{-12}	(>99)
nhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge:	7×10^{-11}	(>99)	3×10^{-11}	(>99)
alation exposure to particulates from il contaminated by land application of sludge:	2×10^{-11}	(>99)	1×10^{-11}	(>99)

Table 2.4.0. (con't.). Best Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge:	5×10^{-10}	(13)	2×10^{-13}	(6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge:	$<2 \times 10^{-12}$	(0.2)	$<2 \times 10^{-12}$	(0.2)
Ingestion exposure to fish caught in surface water contaminated by runoff from areas contaminated by land application of sludge:	1×10^{-8}	(97)	2×10^{-13}	(92)
Ingestion exposure to fish caught by recreational fishing in surface water contaminated by runoff from areas contaminated by land application of sludge:	1×10^{-8}	(97)	1×10^{-12}	(92)
Dietary exposure from produce grown in soil contaminated by land application of sludge:	7×10^{-8}	(>99)	7×10^{-14}	(>99)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table 2.4.P. Best Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (>99)	3×10^{-6} (>99)	40	2×10^{-6} (>99)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-4} (>99)	4×10^{-7} (>99)	40	2×10^{-7} (>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-5} (>99)	7×10^{-6} (>99)	40	4×10^{-6} (>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	5×10^{-6} (>99)	3×10^{-6} (>99)	40	2×10^{-6} (>99)

Table 2.4.P (con't.). Best Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-4} (13)	5×10^{-8} (6)	2,783,000	2×10^{-3} (6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c] (0.2)	$<6 \times 10^{-7}$ (0.2)	$<6 \times 10^{-7}$	NA[d]	NA[d]
Ingestion exposure to fish contaminated by urface runoff from areas contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-3} (96)	5×10^{-8} (92)	6,100,000	4×10^{-3} (92)
Ingestion exposure to fish caught by recreational fishing in surface runoff areas contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-3} (96)	4×10^{-7} (92)	224,000	1×10^{-3} (92)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-2} (>99)	2×10^{-8} (>99)	240,000,000	7×10^{-2} (>99)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

is assumed to be used by nearly 3 million persons. As a result, the dietary pathway yields the largest number of cancer cases per year of any of the land application pathways analyzed (7 x 10^{-2} cases per year). Exposure through drinking of contaminated surface water leads to 2 x 10^{-3} cases per year.

The "most exposed individual" risk is typically one to two orders of magnitude higher than typical risks for the first four pathways shown on this table. The MEI and typical individual risk estimates are close for these pathways because both the "typical" and "MEI" risks from these pathways are evaluated for onsite residents of two agricultural land application sites. In contrast, MEI risks are five to six times higher than typical individual risks from the dietary, drinking water and fish ingestion pathways. For these three pathways, typical risks are estimated for an offsite population, while the MEI risk is assessed for an individual living on the land application site. The highest MEI risks are from the ingestion of produce, meat and dairy products grown on sludge-amended land and from the ingestion of fish caught in contaminated surface water bodies. For the produce and meat ingestion pathway, the MEI is assumed to be a farmer who raises his/her own meat and dairy products on sludge-amended agricultural land. For the fish ingestion pathway, the MEI is assumed to take fish from a relatively small stream from the location in the stream with the maximum dissolved concentrations of TCDD and TCDF. The MEI risk associated with the ingestion of contaminated produce and meat is 2 x 10^{-2}, while the MEI risk from the fish ingestion pathway is 4 x 10^{-3}.

For the dermal contact, direct ingestion, vapor inhalation, particulate inhalation, and produce ingestion pathways, TCDD dominates the MEI risk. For these pathways, the MEI is assumed to reside at an agricultural site. The sludge applied at the two agricultural sites assessed in this analysis has lower TCDF concentrations than TCDD concentrations. In Mississippi, a value of zero is reported for the concentration of TCDF in its sludge, while in Pennsylvania, the reported concentration of TCDF is 3.4 times lower than the reported TCDD concentrations. As a result, all of the risks for pathways that assume that the MEI lives on an agricultural site are dominated by TCDD.

The fish ingestion pathway MEI risk is also dominated by TCDD. This result is due to the higher sediment partitioning coefficient assumed for TCDD. In contrast, the surface water and groundwater ingestion pathway MEI risks are dominated by TCDF. This is due to the assumption that the solubility of TCDF is higher than the solubility of TCDD, resulting in higher dissolved concentrations of TCDF in water.

REFERENCES FOR SECTION 2.4

Bovard, K.P., J.P. Fontenot, and B.M. Priode (1971). Accumulation and dissipation of heptachlor residues in fattening steers. J. Anim. Sci. 33:127-132.

Consumer Product Safety Commission (1989). "Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Di-benzo-p-dioxins and Dibenzofurans," memorandum dated July 6 from M. Babich.

Delta Western Feed Mills, Mississippi (1989). Personal Communication. July.

Food and Drug Administration (1989). "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo dated June 22 from Ivan Boyer.

Fries, George. (1982). Potential polychlorinated biphenyl residues in animal products from application of contaminated sewage sludge to land. Journal of Environmental Quality., Vol. 11, no. 1.

Geyer, H. J. Scheunert, I., Filser, J. G. and F. Korte (1986). Bioconcentration potential (BCP) of 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) in terrestrial organisms including humans. Chemosphere 15:(9-12) 1495-1502.

Hawley, J.K. (1985). Assessment of health risk from exposure to contaminated soil. Risk Analysis 5(4):289-302.

Keenan, R.E., Sauer, M., Lawrence, F., Rand, E., and D. Crawford (1989). "Examination of potential risks from exposure to dioxin in sludge used to reclaim abandoned strip mines." In: The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. D.J. Paustenbach, ed. J. Wiley and Sons, New York, pp. 935-998.

Kimbrough, R., Falk, H. and P. Stehr (1984). Health implications of 2,3,7,8-TCDD contamination of residential soil. J. Tox. Envir. Health 14:47-93.

Martin, S.G., Thiel, D.A., Duncan, J.W., and W.R. Lance (1987). "Effects of a paper industry sludge containing dioxin on wildlife in red pine plantations." In: Proceedings of 1987 TAPPI Environmental Conference.

National Council of the Paper Industry for Air and Stream Improvement (NCASI) (1984). The Land Application and Related Utilization of Pulp and Paper Mill Sludges. Technical Bulletin Number 439, August.

National Council of the Paper Industry for Air and Stream Improvement, Inc (NCASI) (1987). Assessment of Human health Risks Related to Exposure to Dioxin from Land Application of Wastewater Sludge in Maine. June.

National Research Council Canada (1981). Polychlorinated Dibenzo-p-Dioxins: Criteria for Their Effects on the Environment. NRCC Document Number 18574.

Pocchiari, F., F. Cattabein, G.D. Porta, U. Fortuniat, V. Silarno, and G. Zapponi (1986). "Assessment of exposure to 2,3,7,8-TCDD in the Seveso area." Chemosphere. 15(9-12): 1851-1865. Cited in Wisconsin Department of Health and Social Services (1989). "Human Exposure Assessment for Dioxin and Furan Contaminated Papermill Sludge Applied to Soils". Final Draft.

Rumsey, T.S., and J. Bond. (1974). The effect of urea, diethylstilbestrol and type of diet on distribution of aldrin and dieldrin residues in finished beef heifers. J. Agric. Food Chem. 22:664-667.

Sacchi, G.A., P. Vigano, G. Fortunati, and S.M. Cocucci. (1986). "Accumulation of 2,3,7,8-Tetrachlorodibenzo-p-dioxin from soil and nutrient solution by bean and maize plants". Experientia 42:586-588.

Schaum, J. (1984). Risk analysis of TCDD contaminated soils. U.S. EPA, Office of Health and Environmental Assessment, EPA 600//84-4/031, November.

Science and Education Administration and the U.S. Department of Agriculture in Cooperation with Perdue Agricultural Experimental Station (1978). "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning." December.

U.S. Department of Agriculture (1978). "National Food Consumption Survey 1977-1978." Report Number H-6. Human Nutrition Information Service. NFCS-1977-78.

U.S. Department of Agriculture (1982). Food and Nutrition Service, "Commodity Maps". Prepared by Schnittker Associates. Washington, D.C. December.

U.S. Department of Agriculture (1985). Agricultural Statistics 1985. United States Government Printing Office. Washington, D.C.

U.S. Department of Commerce (1987). Bureau of the Census. Statistical Abstract of the United States.

U.S. EPA, Office of Air Quality, Planning and Standards (1984). National Air Quality and Emissions Trends Report, 1982. EPA-450/4-84-002, March.

U.S. EPA (1985a). "TCDD Transport from Contaminated Sites to Exposed URE Loactions: A Methodology for Calculating Conversion Factors." Final Report. G.W. Dawson, et al., Batelle Project Management Division, Richland, WA, June.

U.S. EPA (1985b). Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments. EPA/600/8-85/010, August. Prepared by GCA Corp., Chapel Hill, N.C.

U.S. EPA (1987a). "Comparison of Food Consumption Data". Tolerance Assessment Program, Office of Pesticides and Toxic Substances. Washington, D.C.

U.S. EPA (1987b). Office of Health and Environmental Assessment, Evaluation and Criteria Assessment Office. Development of Risk Assessment Methodology for the Land Application and Distribution and Marketing of Municipal Sludge. August, final draft version.

U.S. EPA (1987c). The National TCDD Study: Tiers 3, 5, 6, and 7. Office of Water Regulations and Standards. EPA 440/4-87-003.

U.S. EPA (1988a). Office of Health and Environmental Assessment, Exposure Assessment Group. Estimating Exposure to 2,3,7,8-TCDD. Draft Report March.

U.S. EPA (1988b). Office of Water Regulations and Standards, Technical Support Document for the Land Application and Distribution and Marketing of Sewage Sludge. Draft Report, August.

U.S. EPA (1988c). Risk Assessment for Dioxin Contamination, Midland, Michigan. EPA-905/4-88-005. April.

U.S. EPA (1989a). "Interim Final Guidance for Soil Ingestion Rates." Office of Solid Waste Emergency Response Directive Number 9850.4, January 27 from J. Winston Porter.

U.S. EPA, Office of Water Regulations and Standards (1989b). Human Health Risk Assessment for Municipal Sludge Disposal: Benefits of Alternative Regulatory Options, February.

U.S. EPA (1989c). Office of Toxic Substances. Graphic Exposure Modelling System: User Guide. March.

U.S. EPA (1989d). Health and Environmental Review Division memorandum to Greg Schweer, Office of Toxic Substances, U.S. EPA, on dioxins in paper products: bioavailability by inhalation. Memorandum dated June 16 from F.J. DiCarlo.

U.S. EPA (1989e). Memorandum to Dioxin-in-Paper Workgroup, on the bioavailability of dioxins in paper products, dated June 23 from C. Cinalli and Conrad Flessner.

U.S. EPA (1989f). 104-Mill Data Base. Office of Water Regulations and Standards, July 17 version.

U.S. EPA (1989g). Memorandum to Dioxin-in-Paper Workgroup, dated July 21 from C. Cinalli.

U. S. EPA (1989h). "Memorandum: OTS/EEB Aquatic Life Hazard Assessment (Including BCF Values) for 'Dioxin in Paper'." Office of Pesticides and Toxic Substances. Washington, D.C. Memorandum dated August 8.

United States Geological Survey (1985). "National Water Summary - 1985". Washington, D.C.

Wipf, H.K., E. Homberger, N. Neuner, U.B. Ranalder, W. Vetter, and J.P. Vuilleumier (1982). "TCDD levels in soil and plant samples from the Seveso area." In: Huntiziger, O., R.W. Frei, E. Merian, and F. Pocchiari, editors. Chlorinated Dioxins and Related Compounds: Impact on the Environment, Pergamon Press, New York.

Young, A.L. (1983). "Long-term studies on the persistence and movement of TCDD in a natural ecosystem." In: Tucker, R.E. A.L. Young, and A.G. Gray, editors. Human and Environmental Risks of Chlorinated Dioxins and Related Compounds, Plenum Press, New York.

2.5 Exposure and Risks from Distribution and Marketing of Pulp and Paper Sludge

Sludge that is composted and marketed can be used as a soil amendment in residential settings as well as for agricultural and commercial purposes. According to the 104-Mill Study, seven mills in five states distribute and market at least a portion of their sludge. Based on data from the 104-Mill Study, the total volume of sludge distributed and marketed by these plants is estimated to be 208,000 dry metric tons per year. In some cases, the plants in this study reported two methods of sludge disposal, but did not provide a break-down of the quantities of sludge disposed by each method. In these cases, it is assumed the entire quantity of sludge by the plant produced is distributed and marketed. To the extent that this assumption overestimates the quantity of sludge distributed and marketed every year, the population risk estimates derived from this analysis will overestimate the true population risk.

This analysis estimates risks to members of households using composted sludge from the following routes of exposure:

- Home gardeners incorporate distributed and marketed sludge to home gardens. The home-grown crops incorporate small amounts of contaminant into their tissues. Household residents then consume the home-grown crops.

- Home gardeners incorporate distributed and marketed sludge into their home gardens, or use it for other home gardening purposes, such as lawns or flower beds. Children and adults in the gardening household come into direct dermal contact with the sludge. TCDD and TCDF from the sludge is absorbed through the skin.

- Children ingest small amounts of the sludge/soil mixture through normal mouthing behavior. Adults also inadvertently ingest small quantities of sludge/soil.

- TCDD and TCDF in distributed and marketed sludge volatilizes from the sludge into the air. Residents of the household inhale the volatilized TCDD and TCDF.

- Distributed and marketed sludge is applied to home gardens or other home uses. Particles of the sludge/soil mixture become suspended in the air. Members of the household inhale the contaminated particles.

Since the actual users of distributed and marketed sludge are not known, a generic scenario is used to estimate risks from the distribution and marketing of sludge. In this scenario, a household uses composted sludge as a soil amendment for ornamental or vegetable gardening. "Low risk," "best" and "high risk" estimates are derived for typical exposure, while "best" and "high risk" estimates are derived for MEI exposure. The following discussion briefly describes the scenario considered to obtain these estimates, as well as the data sources used to construct the generic scenario. The estimated soil concentrations used in the "low risk," "best estimate," and "high risk" scenarios for typical exposures are shown in Table 2.5.A. The highest soil concentration presented in this Table is used in the MEI analysis. Other parameters that describe the generic scenario, as well as the physical chemical parameters of TCDD and TCDF, used in the typical exposure scenario are presented in Table 2.5.B. Parameter values used in the MEI exposure assessment are shown in Table 2.5.C.

Description of Distribution and Marketing Scenario

According the National Gardening Survey (1987), 34 million of the 69 million households involved in gardening activity in 1986 grew vegetables. Based on these data, the best estimate of typical exposure assumes that approximately one-half of the distributed and marketed sludge goes to households with vegetable gardens, while the other half goes to households that use the sludge for ornamental gardening. Furthermore, best estimate typical analysis assumes that households using sludge for ornamental gardening apply sludge at the same rate as households with vegetable gardens. For the "high risk" typical exposure scenario, it is assumed that all of the distributed and marketed sludge goes to households with vegetable gardens. This assumption is also made for the MEI analysis.

The concentrations of TCDD and TCDF in sludge from plants that distribute and market sludge were obtained from the 104-Mill Study. The methods for calculating the soil concentration of TCDD and TCDF in home garden soils amended with the composted sludge are described in Appendix A. The soil concentration model requires inputs for the initial TCDD and TCDF concentrations, length of the application period and the depth of incorporation with background soils. Decay of TCDD and TCDF during the composting process is assumed to be negligible. The analysis assumes that composted sludge is applied to a home garden for 20 years. The home gardener continues to use the garden for an additional fifty years.

In the "low risk" and "best estimate" typical exposure scenarios, the analysis assumes that sludge is soil incorporated. For the "high risk" typical exposure scenario, it is assumed that sludge is applied only to the top layer of soil. USDA (1979) recommends depths of incorporation for the maintenance of crops ranging from approximately 6 to 10 inches. Sludge may also be applied without

Table 2.5.A. Distribution and Marketing Sludge and Soil Contaminant Concentrations[*]

Plant Number	State in which plant is located	Sludge concentration		Soil concentration, assuming 10 inches depth of incorporation		Soil concentration, assuming 6 inches depth of incorporation		Soil concentration, assuming no soil incorporation	
		Dioxin PPT	Furan PPT	Dioxin PPT	Furan PPT	Dioxin PPT	Furan PPT	Dioxin PPT	Furan PPT
1	California	60.7	1113	1.15	21.1	3.8	69	60.7	1113
2	Pennsylvania	2	1.1	0.04	0.02	0.1	0.07	2	1.1
3	Washington	4.9	51.7	0.09	1	0.3	3.2	4.9	51.7
4	Ohio	17**	244**	0.3	4.6	1.1	15	17	244
5	Pennsylvania	14	44.9	0.3	0.9	0.9	2.8	14	44.9
6	Texas	17**	244	0.3	4.6	1.1	15	17	244
7	Texas	2.8	8.5	0.05	0.2	0.2	0.5	2.8	8.5

[*] average concentrations over 70 years of expsoure, assuming sludge is applied to land for 20 years

[**] used the average concentration for plants practicing D&M

Table 2.5.B. Parameters and Model Inputs for Typical Exposure Analysis Used to Model Distribution and Marketing

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of sludge to home garden vs. other uses	50%	50%	100%	Best estimate and low: based on analysis of National Garden Survey, 1987. High: maximum value possible.	National Garden Survey, 1987
Soil Incorporation Assumptions	10 inches	6 inches	0 inches		USDA "Use of Sewage Sludge Compost for Soil Improvement and Plant Growth." ARM-NE-6, August 1979.
Garden Size (hectares)	0.016	0.016	0.022		National Garden Survey (1987)
Application Rate (DMT/year)	5	10	20		USDA (1979)

Table 2.5.B. (cont.) **Parameters and Model Inputs for Typical Exposure Analysis Used to Model Distribution and Marketing**

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec),	0.05	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	57	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	2.12×10^{-6}	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 2.5.B. (cont.) Parameters and Model Inputs for Typical Exposure Analysis Used to Model Distribution and Marketing

nput arameter	Low	Best estimate	High	Notes/explanation	Reference
CDF ffusivity in ir (cm^2/sec)	0.05	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
ffusivity in ater m^2/sec)	5.6×10^{-6}	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
solubility water /g)	4.3	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
photolysis life of r (min)	57	4,320	infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
molecular ght	306	306	306		
Koc	4.1×10^4	3.5×10^4	3.5×10^4		Both values from ChemEst procedure in Gems. Low value from Karickhoff method; best and high estimates from Kenaba method.
Henry's Constant ^{3}/mol	8.6×10^{-5}	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

Table 2.5.C. Parameters and Model Inputs Used to Model for MEI Analysis: Distribution and Marketing

Input parameter	Best estimate	High	Notes/explanation	Reference
Percent of sludge to home garden vs. other uses	100%	100%	Maximum value possible.	National Garden Survey, 1987
Soil Incorporation Assumptions	0 inches	0 inches	Topdressing scenario.	
Garden Size (hectares)	0.22	0.022	Size of rural garden.	National Garden Survey (1987)
Application Rate (DMT/year)	20	20		USDA (1979)

Table 2.5.C. (cont.) Parameters and Model Inputs Used to Model for MEI Analysis: Distribution and Marketing

Input parameter	Best estimate	High	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	--	No photolysis assumed for high risk estimate.	Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}		Value from Podol (1986).

Table 2.5.C. (cont.) Parameters and Model Inputs Used to Model for MEI Analysis: Distribution and Marketing

Input parameter	Best estimate	High	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	Infinite	Assumed same as TCDD. No photolysis assumed for high-risk estimate.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306		
TCDF Koc	3.5×10^4	3.5×10^4		Value from ChemEst procedure in Gems. Estimates from Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

incorporation (i.e., top dressing). In the "best estimate" scenario, this analysis used 6 inches of incorporation. Assuming 10 inches of incorporation yields a lower exposure estimate due to greater dilution of the sludge contaminants, while assuming the top-dressing scenario yields a higher exposure estimate. The top-dressing scenario is used to model risks to the MEI.

Data Sources and Model Inputs for Application Rates

The best estimate for typical exposure assumes that the home gardener applies 10 dry metric tons of sludge per hectare per year to his or her home garden. The recommended application rates for home uses ranges from 5 to 20 dry metric ton per hectare (USDA, 1979). However, assuming a higher (or lower) application rate forces a smaller (or larger) estimate of the number of households affected, as long as there is a constant amount of sludge dedicated to home uses. Population cancer risks are relatively insensitive to this parameter as long as cancer risks are assumed to have no threshold. MEI risks are affected by this assumption, however. The MEI was assumed to apply 20 metric tons per year to his/her home garden.

The size of the garden assumed in the generic scenario affects the individual risks estimates and influences the estimate of the size of the exposed population. According to the National Garden Survey (1987) the average garden size for combined rural and urban vegetable gardens is 0.016 hectares. For the "high risk" scenario, the average rural garden size (0.022 hectares) is assumed. The MEI is assumed to have a garden 0.022 hectares in size.

Using the generic scenario described above, this analysis estimates exposures from dermal contact, vapor and particulate inhalation, and direct ingestion for young children (ages 1-6), older children (ages 7-12) and for adults, while dietary exposures are estimated for young children (1-6) and adults. The average daily exposure over a lifetime from each of these pathways is the weighted average of the daily exposures during these stages of life. These exposures are combined with cancer slope factors to obtain incremental lifetime risk from TCDD and TCDF exposure. The following sections describe the methods and data used to estimate risks from home uses of distributed and marketed sludge through each these pathways. Results are summarized in the final section.

2.5.1 Estimates of Exposure and Risks from Dermal Contact with Skin

Humans coming in direct contact with sludge contaminated soils may absorb TCDD and TCDF through their skin. The amount of TCDD and TCDF absorbed will depend on the area of skin exposed and on the length of time that the contaminated soil is in contact with the skin. The following discussion summarizes the model used to estimate exposure through dermal contact with composted pulp and paper mill sludges used in residential settings.

To estimate exposure through direct contact with soil containing TCDD and TCDF, methodologies presented in Schaum (1984), Hawley (1985), and EPA (1988a) were used. The model uses empirically-derived information on the amount of soil or dust that adheres to a square centimeter of skin, the area of skin exposed in various settings and the absorption rate of TCDD or TCDF through skin to derive the dose of TCDD or TCDF from dermal contact with contaminated soil or dust.

Description of Calculations

The calculation of dermal exposure proceeds in two steps. First the average daily exposure from dermal contact is calculated as the product of area of skin affected, the contact rate, the dermal absorption rate and the duration of contact. Second, the risk from dermal contact is calculated using the estimate of daily exposure and the slope factors of TCDD and TCDF.

Description of Exposure Calculations

The concentration of TCDD and TCDF in the soil in home gardens or lawns is derived as described in Appendix A. Contaminated soil may also be brought indoors through airborne dust particles, and/or tracking of dirt on clothes and shoes. The concentration of TCDD and TCDF in indoor dust is calculated as follows:

$$C_{in} = C_o F$$

where:

C_{in} = concentration of TCDD or TCDF in dust indoors, mg/mg
C_o = concentration of TCDD or TCDF in soil outdoors, mg/mg
F = ratio of indoor concentrations to outdoor concentrations

The indoor dust and outdoor soil contaminant concentrations are used to estimate human exposure and risk from dermal contact with these media. Daily doses are estimated for three age groups: young children (ages 1-6), older children (ages 7-11) and adults (ages 12 and older). The dose for each age group is calculated as:

$$DOSE_g = [(C_o \, CR_{o,g} \, SA_{o,g} \, H_{o,g} \, AB_d \, M) + (C_{in} \, CR_{in,g} \, SA_{in,g} \, H_{i,g} \, AB_d \, M)] / BW_g$$

where:

AB_d = systemic absorption rate through the skin
BW_g = body weight = 70 kg for adult, 16 kg for young child, 35 kg for older child
C_o = concentration of TCDD or TCDF in soil outdoors, mg/mg
C_{in} = concentration of TCDD or TCDF in dust indoors, mg/mg
$CR_{in,g}$ = contact rate of soil with skin for age group g, indoors, mg/cm^2
$CR_{o,g}$ = contact rate of soil with skin for age group g, outdoors, mg/cm^2
$DOSE_g$ = dose from outdoor exposure for age group g, mg/kg/day
$H_{i,g}$ = hours spent indoors for age group g
$H_{o,g}$ = hours spent outdoors for age group g
$SA_{in,g}$ = surface area of skin exposed to soil for age group g, indoors, cm^2
$SA_{o,g}$ = surface area of skin exposed to soil for age group g, outdoors, cm^2
M = matrix effect on absorption rate, percent

For each age group, the soil contaminant concentration (expressed in mg/mg for ease of calculation) is multiplied by the soil contact rate outdoors (mg/cm^2) and by the area of the skin exposed during outdoor activity (cm^2) to obtain the total quantity of soil-bound TCDD or TCDF adhering to the skin (mg). The quantity of contaminant on the skin is then adjusted by two factors: the fraction of the contaminant that migrates from the soil matrix and comes into contact with the skin; and the fraction of TCDD or TCDF that absorbs through the skin. Since the dermal absorption rate is expressed as the fraction of TCDD or TCDF that is absorbed through the skin per hour of contact, it must be multiplied by the hours that the soil is assumed to be in contact with the skin. The same calculations are also performed for exposures in indoor settings, using the corresponding indoor values for the model input parameters. The total daily dermal absorption of TCDD or TCDF is the sum of indoor absorption and outdoor absorption. Dividing the total dermal absorption for each age group by the body weight for that age yields a daily dose of TCDD or TCDF through dermal absorption in mg/kg/day.

To obtain the weighted average dose over the lifetime of an individual, the following calculation is used:

$$DOSE_{avg} = \Sigma \, FRAC_g (DOSE_g)$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
$DOSE_g$ = daily dose for individual in age group g
$FRAC_g$ = fraction of lifetime spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with information about the slope factor of TCDD and TCDF to obtain an estimate of lifetime risk from dermal exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg}\ q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

This calculation is performed for both a typical and the most exposed individual. Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC\ POP / LS$$

where:

LS = average lifespan of an individual = 70 years
PC = population risk, cancer cases per year
POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs

The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.5.D. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.5.E. The best MEI exposure estimate is derived using by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical ~~and MEI~~ analyses. Where parameter input values differ

Table 2.5.D. Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	0.13	0.5	1.5	Roels (1980) used in Schaum (1984) to develop high value; Lepow (1975) cited by Schaum for best estimate value; low value from Roels 1980, cited in Hawley, 1985.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	0.13	0.5	1.5	Roels (1980) used in Schaum (1980) high value; Lepow (1975) cited by Schaum for best estimate value; low value from Roels (1980) cited in Hawley, 1985.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	0.13	3.5	3.5	Best estimate: value from Hawley (1985) based on adults doing yard work Low: based on low value for children given by Hawley (1985) based on Roels (1980).	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.011	0.056	0.06	Low and high values are from Solomon and Hartord (1976) as cited by Hawley. Best estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.011	0.056	0.06	Low and high values are from Solomon and Hartord (1976) as cited by Hawley. Best estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space, indoor, adult attic	0.011	0.056 1.8 (110 mg/hr)	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985

Table 2.5.D. (cont.) Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Ratio of contaminant concentration indoors to soil concentration outdoors	0.75	0.80	0.85		Hawley, 1985
Time spent outdoors, child (hr)	1565	1565	2190	Low and best estimate: assumes 5 days/wk, 6 months/yr, 12 hrs/day (12 hrs before soil is washed off) High: 7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	1824	1824	2190	Low and best: child outdoors from May to September every day (150 days), 12 hrs of soil contact before washing High estimate: child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	168	348	1565	Low: assumes 8 hrs of soil contact, 1 day/wk, 5 months Best: assumes 8 hrs of soil contact before washing, 2 days/wk for 5 months High estimate: assumes 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Best: Hawley, 1985 High: Adopted from Keenan, 1989
Time spent indoors, child (hr)	4380	4380	6570	Low and best: 12 hrs/day of indoor dust contact all year High: assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989

Table 2.5.D. (cont.) Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Time spent indoors, older child (hr)	1460	1460	4380	Low and best: assumes 4 hrs/day of indoor dust contact all year High: assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985
Time spent indoors, adult (hr) living space, attic	4380 16	4380 48	6570 72	Living space: low and best estimate assumes indoor dust contact 12 hrs/day, all year; high assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months. Attic: low assumes 1 day in attic with soil left on skin for 12 hrs while in attic plus 4 hrs before washing. Best estimate assumes 12 days with soil on skin 4 hrs/day. High assumes 12 days with soil on skin 6 hrs/day.	Adopted from Hawley, 1985
Area of skin exposed outdoor, child (cm^2)	300 cm^2	2100 cm^2	2800 cm^2	Low assumes only hands exposed (child wearing pants and long-sleeved shirt). Best estimate assumes both hands, legs and feet exposed during play. High assumes both hands, arms, legs and feet exposed.	Hawley, 1985
Area of skin exposed outdoor, older child (cm^2)	400 cm^2	1600 cm^2	3200 cm^2	Low assumes only hands exposed. Best estimate assumes both hands, forearms, legs from knees down exposed during play. High assumes both hands, legs and feet exposed during play.	Low and best estimate: Hawley, 1985 High: assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	910 cm^2	1700 cm^2	2940 cm^2	Low assumes adult is wearing long-sleeved shirt, gloves, pants, shoes. Best assumes both hands, most of forearms exposed. High assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Low: Schaum, 1984 (citing Sendroy, 1954) Best estimate: Hawley, 1985 High: Schaum, 1984 (citing Sendroy, 1954)

Table 2.5.D. (cont.) Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Area of skin exposed indoor, child (cm^2)	300 cm^2	500 cm^2	1000 cm^2	Low assumes only both hands exposed. Best estimate assumes area exposed equals one half of surface area of childs feet, hands and forearms. High assumes all of area of feet, hands and forearms.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	400 cm^2	400 cm^2	825 cm^2	Low and best estimate assume only hands are exposed. High assumes only forearms and hands exposed.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	900 cm^2 (living space) 1700 cm^2 (attic)	900 cm^2 (living space) 1700 cm^2 (attic)	1700 cm^2 in both attic and living space	Low and best estimate assumes hands exposed in living space, while adult wears short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat, to work in attic. High assumes adult exposed to indoor dust while wearing short-sleeved shirt with an open neck, pants, shoes, no gloves or hat.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1}	0.012 h^{-1}	0.024 h^{-1} (children only)	Low and best: Bioavailability Workgroup. High: Hawley (1985) assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.
Availability of dioxin from soil matrix	0.3%	1%	15%	Recommended value: 1%	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

Table 2.5.E. Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	1.5	1.5	Roels (1980) used in Schaum (1984) to develop value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	1.5	1.5	Roels (1980) used in Schaum (1980) to develop value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	3.5	3.5	Value from Hawley (1985) based on adults doing yard work.	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.06	0.06	Value from Solomon and Hartord (1976) as cited by Hawley.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.06	0.06	Values are from Solomon and Hartord (1976) as cited by Hawley.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space, indoor, adult attic	0.06 1.8 (110 mg/hr)	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985

Table 2.5.E. (cont.) Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Ratio of contaminant concentration indoors to soil concentration outdoors	0.80	0.85		Hawley, 1985
Time spent outdoors, child (hr)	2190	2190	7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	2190	2190	Assumes child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	1565	1565	Assumes 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Best: Hawley, 1985 High: Adopted from Keenan, 1989
Time spent indoors, child (hr)	6570	6570	Assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989

Table 2.5.E. (cont.) Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Time spent indoors, older child (hr)	4380	4380	Assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985
Time spent indoors, adult (hr) living space, attic	6570 72	6570 72	Living space: Assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months. Attic: Assumes 12 days with soil on skin 6 hrs/day.	Adopted from Hawley, 1985
Area of skin exposed outdoor, child (cm^2)	2800 cm^2	2800 cm^2	Assumes both hands, arms, legs and feet exposed.	Hawley, 1985
Area of skin exposed outdoor, older child (cm^2)	3200 cm^2	3200 cm^2	Assumes both hands, legs and feet exposed during play.	Low and best estimate: Hawley, 1985 High: assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	2940 cm^2	2940 cm^2	Assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Low: Schaum, 1984 (citing Sendroy, 1954) Best estimate: Hawley, 1985 High: Schaum, 1984 (citing Sendroy, 1954)

Table 2.5.E. (cont.) Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Dermal Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Area of skin exposed indoor, child (cm^2)	2800 cm^2	2800 cm^2	Assumes same area of skin exposed indoors as outdoors.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	3200 cm^2	3200 cm^2	Assumes same area of skin exposed indoors as outdoors.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	2940 cm^2 in both attic and living space	2940 cm^2 in both attic and living space	Assumes same area of skin exposed indoors as outdoors.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1} adults; 0.024 h^{-1} children	0.012 h^{-1} adults; 0.024 h^{-1} children	Children's value from Hawley (1985), who assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989; Hawley, 1985
Availability of dioxin from soil matrix	15%	15%		"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for Soil Concentrations

The method for deriving soil concentrations is described in Appendix A. Soil concentrations resulting from the use of composted sludge from each plant that distributes and markets sludge are presented in Table 2.5.A.

Data Sources and Model Inputs for Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

Roberts et al. (1977), as discussed by Hawley (1985), studied the relationship between lead concentrations indoors and outdoors near a lead smelter, and found that the mean concentration of the lead in household dust was 75% the concentration of lead in the outdoor soil. For his own analysis, Hawley (1985) assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The typical exposure analysis uses a value of 80% for the best estimate, and applies a range of 75% to 85% for the low and high estimates respectively. For the "best estimate" MEI calculation, a value of 80% is used, while 85% is used for the "high risk" MEI exposure estimate.

Data Sources and Model Inputs for Contact Rate

The contact rate of soil on skin varies between outdoor and indoor exposures and among age groups. Hawley (1985) and Schaum (1984) both described a number of studies that estimated the contact rate of soil on the skin of children playing outdoors. Lepow et al. (1975), as cited in Hawley (1985), estimated a contact rate of 11 mg soil per 21 cm^2 of skin on the hands of young children, or 0.5 mg/cm^2. Exposed skin on other parts of the body is assumed to have the same contact rate. Roels et al. (1980), as cited in Hawley (1985) found that the mean values for quantity of dirt on one hand of eleven-year old children ranged from 40 to 180 mg. Since the hand of a child this age has a surface area of approximately 300 cm^2, these data suggest a contact rate ranging from 0.13 to 0.6 mg/cm^2. Schaum (1984) reported the upper end of the estimate for outdoor contact rate for children to be 1.5 mg/cm^2. In the analysis of typical exposures, 0.5 mg/cm^2 is used for the best estimate, 0.13 mg/cm^2 the low estimate, and 1.5 mg/cm^2 the high estimate of contact rate for both young and older children. The MEI analysis assumes an outdoor soil contact rate of 1.5 mg/cm^2 for both young and older children.

For adults, the outdoor contact rate was derived by Hawley (1985), based on assumed thickness of the layer of soil on the skin and the density of outdoor soil. Hawley's calculations yielded a value of 3.5 mg/cm^2. This value is used in the "best" and "high risk" typical exposure estimates and for the MEI analysis. For the "low risk" typical exposure estimate, the analysis uses the low estimate for outdoor contact rate in children.

Hawley (1985) estimated indoor contact rates based on assumptions regarding dustfall and frequency of cleaning. Hawley also cited the work of Solomon and Hartford (1976), who studied lead and cadmium levels in indoor dust. The dust values measured by these researchers ranged from 110 mg/m^2 to 590 mg/m^2. For his analysis, Hawley (1985) used a value of 0.056 mg/cm^2 for indoor dust contact rate, assuming a dustfall rate indoors that is 20% of the outdoor dustfall, and assuming biweekly cleaning of surfaces. The typical exposure analysis uses Hawley's value as a best estimate, and uses the range of values reported by Solomon and Hartford (1976, through Hawley, 1985) as low and high estimates. These values are used to represent contact rate indoors in living space for all three age groups. A value of 0.06 mg/cm^2 is used for the MEI analysis.

Adults may also experience dermal contact with soil when engaged in infrequent cleaning of seldom-used spaces, such as attics. After a discussion of the relevant literature, Hawley (1985) concluded that an adult working for a one-hour exposure in a dusty space such as an attic has indirect dermal contact with 110 mg of dust suspended in air. In addition, the direct contact rate with dust was estimated to be 1.8 mg/cm^2, based an assumed depth of the dust layer on the skin and the density of indoor dust particles. To assess risks from these exposures, the analysis of Hawley (1985) is incorporated into the typical and MEI analyses.

Data Sources and Model Inputs for Area of Skin Exposed

The surface area of skin available for contact with contaminated soil will influence the quantity of TCDD and TCDF absorbed through this pathway. The surface area available for contact will vary depending on the clothing worn by the individual. Hawley (1985) provides a table of surface area for various parts of the body for young children, older children, and adults. In the following discussion, the area of the skin assumed to be exposed in each scenario for each age group is derived from this table. The assumptions regarding the body parts exposed in each scenario are also derived from Hawley (1985), except as noted.

For the best estimate of typical exposure, it is assumed that the feet, legs and hands of young children are exposed to soil during outdoor play, an area of 2100 cm^2; indoors, one-half of the area of the hands, forearms and feet, or 500 cm^2 is assumed to be exposed. The low estimate of typical exposure assumes that only the child's hands are exposed both indoors and outdoors (300 cm^2): the rest of the body is covered with clothing. The "high risk" typical analysis assumes that young children's hands, arms, legs, and feet (2800 cm^2) are exposed outdoors, while feet, hands, and forearms are in contact with indoor dust (1000 cm^2). The MEI analysis assumes that the same area of skin (2800 cm^2) is exposed indoors as is exposed outdoors.

For older children, the typical exposure analysis uses a value of 1600 cm^2 for the best estimate of the surface area of skin exposed while playing outdoors. This value represents exposure of both hands, forearms, and half of the legs (i.e., from the knees down). Indoors, older children have 400 cm^2 of skin in contact with indoor dust, an area equivalent to the area of both hands. For the low estimate of typical exposure, the analysis assumes that only hands are exposed both outdoors and indoors. The high estimate of typical exposure for outdoor exposure is based on Keenan et al. (1989), who assumed that children playing outdoors expose both hands, legs and feet to soil. The surface area corresponding to these parts of the body for older children is approximately 3200 cm^2 (Hawley, 1985). The high estimate of typical exposure indoors for older children assumes that the hands and the forearms of the child, or approximately 825 cm^2 of skin, are exposed. The MEI analysis assumes that the same area of skin (3200 cm^2) is exposed indoors as is exposed outdoors.

The hands and forearms of adults working outdoors are assumed to come into contact with contaminated outdoor soil. The area of these body parts is approximately 1700 cm^2. This value is used in the best estimate of typical exposure. For the low estimate of typical exposure, the analysis uses Schaum (1984), who, citing Sendroy (1954), assumes that adults may wear a long-sleeved shirt, gloves, pants, and shoes to work outdoors. In this case, the area exposed is 910 cm^2. The "high risk" typical estimate and the MEI analysis use Schaum (1984), citing Sendroy (1954), who assumes that adults may wear a short-sleeved shirt with an open neck, pants, shoes, with no gloves or hat, to work outdoors. The area of skin exposed under these assumptions is 2940 cm^2.

For adults indoors, different assumptions can be made for the area of skin exposed while the adult is in the living space and the area exposed while the adult works in an attic. Adults working in the attic are assumed to wear an open-neck, short-sleeved shirt, pants, shoes, and no gloves or hat, while adults in the living space wear clothing that covers a larger area of skin and behave in such a manner that only the hands are in direct contact with indoor dust. This corresponds to an area of 1700 cm^2 in the attic, and 900 cm^2 in the living space. These values are used to calculate both the "low risk" and the "best" estimates of typical exposure. The "high risk" estimate assumes that 1700 cm^2 of skin are exposed in both the attic and in the living space. The most exposed individual is assumed to have the same area of skin exposed indoors as is exposed outdoors.

Data Sources and Model Inputs for Exposure Duration: Indoor and Outdoor Soils

The length of time soil is in contact with the skin is an important factor in determining the amount of TCDD or TCDF that is absorbed into the system through the skin. The following assumptions regarding duration of dermal exposure are derived from Hawley (1985). The typical exposure analysis assumes young children spend 5 days a week, six months out of the year playing outdoors. The outdoor soil is assumed to remain in contact with the skin for twelve hours before it is washed off. The remaining twelve hours are spent in contact with indoor dust. During the winter months, young children are in contact only with indoor dust, for 12 hours per day. In the "high risk" typical and most exposed individual estimates, young children play outdoors seven days per week, six months out of the year, with soil remaining on the skin for twelve hours. The remaining twelve hours are spent in contact with indoor dust. The high risk typical and MEI estimates also assume that young children are in contact with indoor dust 24 hours a day during the six winter months.

As a best estimate, the typical exposure analysis assumes that older children spend some time outdoors everyday between May and September (5 months), and allow the outdoor soil collected on the skin to remain there for twelve hours before washing. In addition, older children are assumed to be in contact with indoor dust for four hours per day all year; the rest of the time is spent at school or other locations. As a "high risk" estimate, and for the MEI analysis, older children are assumed to spend some time outdoors every day for six months, and to allow the soil to remain on the skin for 12 hours before washing; furthermore, these children are in dermal contact with indoor dust for 12 hours every day year round.

Adults from residences that use distributed and marketed sludge are assumed to have a shorter dermal exposure duration than those living on agricultural sites. The typical analysis assumes as a best estimate that dermal contact for adults occurs two days per week, five months of the year; the soil is assumed to remain on the skin for eight hours before washing. The low estimate of typical exposure assumes outdoor dermal exposure occurs only one day per week, eight hours per day, for five months out of the year. For both the "best estimate" and "low risk" estimates, adults are assumed to be in contact with indoor dust for twelve hours a day all year. For the "high risk" typical exposure estimate, and for the MEI, distributed and marketed sludge is assumed to go to farms, where the adult is in dermal contact with contaminated outdoor soil 5 days a week, six months out of the year, for twelve hours per day. Furthermore, the high estimate assumes that adults have dermal exposure to indoor dust for 12 hours a day during the summer months, and 24 hours a day during the winter months.

Adults may also have limited dermal exposure while cleaning seldom-used spaces such as attics. Hawley (1985) assumes that an adult spends 12 hours in these environments during one year. This value could represent a single cleaning, where the adult spends one twelve-hour period in the attic, or it could represent twelve one-hour cleaning sessions. For the best estimate of typical exposure, it is assumed that the adult spends twelve days in the attic, one hour each day, and leaves the dust from attic on the skin for four hours before washing. The "low risk" estimate assumes the adult spends one day in the attic for twelve hours, and leaves the dust on the skin for an additional four hours before washing. In the "high risk" typical estimate and MEI estimate, the adult engages in twelve one-hour attic cleaning sessions, and leaves the attic dust on the skin for six hours after each session.

Data Sources and Model Inputs for Dermal Absorption of TCDD and TCDF

Dermal absorption of TCDD and TCDF bound to soil involves two components: migration of the TCDD and TCDF from the soil matrix, and absorption of TCDD and TCDF through the skin. The Consumer Product Safety Commission (1989) reviewed data pertaining to the dermal absorption of TCDD from a variety of matrices. The Consumer Product Safety Commission (CPSC) memorandum cites studies by Poiger and Schlatter (1980), who reported absorption of TCDD from wet soil ranging from 0.05% to 2.2%, and by Shu et al. (1988), who reported absorption of 0.65% to 1% with dry soil. Comparing these absorption rates to the rate of dermal absorption when TCDD is applied to the skin in a methanol vehicle, CPSC concluded that from 0.3% to 15% of the TCDD in soil is released for subsequent absorption through the skin. For the best estimate of typical exposure, the recommendation of the CPSC memorandum is followed and a value of 1% is used to represent the best estimate for this matrix effect for contaminated soil, while using the range of 0.3% to 15% for the low and high estimates, respectively. For the MEI analysis, a value of 15% is used.

CPSC also reviewed the literature regarding the percutaneous absorption of the TCDD release from the soil matrix. Studies reviewed included studies with laboratory animals and in-vitro studies of human skin. The animal studies report percutaneous absorption rates ranging from 40 to 48% over 72 hours. From the in-vitro skin experiments (Weber et al., as cited in CPSC memorandum), CPSC estimated an absorption rate of 18.5% over 17 hours of exposure, yielding a transfer coefficient of 0.012 h^{-1}. This value is used in the "low risk" and "best" estimate of typical exposure for all age groups. For children, Hawley (1985) states that the absorption rate through skin for children is twice the absorption rate for adults. Therefore, in the "high risk" typical and MEI exposure analyses, a transfer coefficient of 0.024 hr^{-1} is used for the estimate of the percutaneous absorption rate for both younger and older children.

Data Sources and Model Inputs for Calculating Size of the Exposed Population

Table 2.5.F. describes the calculations used to estimate the size of population exposed to distributed and marketed sludge. First, the total tons of sludge to distribution and marketing from each plant engaged in this practice were obtained from the 104-Mill Study. The "best" typical exposure analysis assumes that sludge is applied at a rate of 10 dry metric tons (DMT) per hectare. Dividing tons by the application rate yields the number of acres covered by the distributed and marketed sludge. Next, the size of the average garden is used to determine the number of households using distributed and marketed sludge. According to the National Garden Survey (1987) the average garden size for combined rural and urban vegetable gardens is 0.016 hectares. Dividing acres covered by sludge by the number of acres per household gives the number of households affected. Finally, the number of persons households is multiplied by the average number of persons per household to obtain the total number of persons affected by distributed and marketed sludge. For the "high risk" scenario, the average rural garden size (0.022 hectares) and an application rate of 20 DMT are used to determine exposed population.

2.5.2 Estimates of Exposure from Ingestion of Home-Grown Produce

To model the risks associated with ingestion of home-grown crops, a computer model, written in Borland International's Turbo Pascal computer programming language and executed on an IBM personal computer, is used. Risks through the dietary pathway are calculated by estimating the contaminant concentration in homegrown crops, and then multiplying this concentration by the daily consumption of home-grown vegetables. This analysis assumes that only the residents of the household using the composted sludge are exposed to sludge contaminants. Furthermore, the analysis assumes that home gardeners do not produce meat or dairy products with the distributed and marketed sludge. As described in Table 2.5.F., the total number of households using distributed and marketed sludge is determined based quantity of compost going to residential uses, the average application rate in a residential setting, and size of the average garden; the number of persons potentially exposed is then derived by multiplying the number of households by the average number of persons per household.

For households with vegetable gardens, the calculations proceed in three steps. The first calculation estimates the sludge TCDD and TCDF concentrations in the tissues of crops grown in sludge-amended home gardens. Next, individual risks are estimated based on dietary ingestion of each crop. Finally, risks from all crops are summed to estimate the total cancer risk from TCDD and TCDF through dietary exposures. The calculations for each of these three components is described below.

Table 2.5.F. Estimated Population Affected by D&M Sludge

A)	Average garden size, ha:	0.016[1]
B)	Application rate, DMT/ha:	10[2]
C)	Total sludge to D&M, DMT:	208,000[3]
D)	Number of households:	1,300,000[4]
E)	Persons per household	2.7[5]
F)	Persons exposed:	3,510,000[6]

Notes:

[1] From National Garden Survey, 1987.

[2] From USDA (1979).

[3] From 104 Mill Study.

[4] C/(AxB)

[5] From the U.S. Census, 1980.

[6] D x E

Determining Tissue Concentrations of Contaminants for Produce Grown in Sludge-Amended Gardens

$$CD_i = C_s\ U_i$$
$$CW_i = CD_i\ KDW_i$$

where:

C_s	=	soil concentration of TCDD or TCDF, adjusted for additional mass from added sludge (mg/kg)
CD_i	=	tissue concentration (dry weight) of TCDD or TCDF in crop i (ug/g dry)
CW_i	=	tissue concentration (wet weight) of TCDD or TCDF in crop i (ug/g wet)
KDW_i	=	constant for converting dry weight concentration to fresh weight concentration for crop i
U_i	=	rate of uptake of TCDD or TCDF into tissue of crop i (ug/g dry weight per mg/kg in soil)

The calculations for determining the soil concentration of TCDD or TCDF are described in Appendix A. Once the contaminant soil concentration has been determined, each crop's uptake rate is applied to contaminant amounts to estimate the concentration of TCDD or TCDF per unit of dry-weight of crop tissue. Dry weight tissue concentrations are converted to wet weight concentrations.

Determining Exposure from Contaminant Ingestion through Foods Grown in Sludge-Amended Gardens

$$DOSE_g = \Sigma i\ [CW_i\ \ FC_i\ \ DC_{i,g}\ \ 10^{-3}]$$

where:

CW_i	=	tissue concentration (fresh weight) of TCDD or TCDF in crop i (ug/g wet)
DC_i	=	daily dietary consumption (fresh weight) of crop i (g/kg/day) for age group g
$DOSE_g$	=	total dose of TCDD or TCDF from produce grown in sludge-amended garden for age group g (mg/kg/day)
FC_i	=	fraction of dietary consumption of crop i grown in sludge-amended garden (unitless)
10^{-3}	=	factor for converting g to mg

Daily doses are estimated for children ages 1-6 and for individuals over age 7. Doses of TCDD or TCDF from each food are estimated by multiplying fresh weight contaminant concentrations (ug/g) by the amount of that food crop consumed in the diet (g/kg/day) for each age group and by fraction of the daily quantity consumed that comes from the sludge-amended garden. (Note that the units are adjusted by 10^{-3} to mg/kg/day.) The dose for each food is combined with the dose of TCDD or TCDF from other garden produce to yield a total dietary ingestion of TCDD and TCDF.

The weighted average daily dose of contaminant over an individual's lifetime is calculated as the sum of the daily doses for each age group weighted by the fraction of the individual's lifespan spent as a member of that age group, as described in the following calculation:

$$DOSE_{avg} = \Sigma F_g DOSE_g$$

where:

$DOSE_{avg}$ = average daily dose over lifetime, mg/kg/day
$DOSE_g$ = daily dose for individual in age group g, mg/kg/day
F_g = fraction of an individual's lifetime spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with information about the slope factor of TCDD and TCDF to obtain an estimate of lifetime risk from dietary exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg} \, q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

This calculation is performed for both typical and MEI exposures. Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the typical individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC \ POP / LS$$

where:

LS = average lifespan of an individual = 70 years

PC = population risk, cancer cases per year

POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs for Estimates of Exposure from Ingestion of Home-Grown Produce

The values used for each model input for "low risk," "best" and "high risk" typical dietary exposure estimates are summarized in Table 2.5.G. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.5.H. The "best" MEI exposure estimate is derived using by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for Soil Concentrations

The methods for deriving the soil concentrations in home gardens where composted sludge is applied are presented in Appendix A. The resulting average soil concentrations over 70 years are displayed in Table 2.5.A. Sludge concentrations were obtained from the 104-Mill Study for plants distributing and marketing sludge.

Data Sources and Model Inputs for Plant Uptake Rates

For the typical exposure analysis, uptake rates for all home-grown crops except potatoes and root crops were estimated to be 2 percent, with a range from 0.01% to 15%. The low estimate is derived from a study by Wipf et al. (1982). The "best" estimate uptake value for these crops is based on the recommendation of the Subgroup on TCDD Uptake in Terrestrial Plants (EPA, 1989d). The

Table 2.5.G. Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Dietary Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Plant uptake rates	above-ground: 0.001 root: 0.01	above-ground: 0.02 root: 0.5	above-ground: 0.15 root: 1	Range for whole roots is the range recommended by Subgroup on Dioxin Update in Terrestrial Plants (memo from Christina Cinalli, June 23, 1989).	Above-ground: Low: Wipf, et al., 1982 High: Young, 1983 Best: recommendation of Subgroup on Dioxin Uptake in Plants (6/23/89 memo). Roots: Subgroup on Dioxin Uptake in Terrestrial Plants (6/23/89 memo).
Fraction of vegetables from home garden	0.05 for all vegetables but legumes; 0.01 potatoes; 0.03 dried legumes.	0.27 for all vegetables but legumes; 0.15 potatoes; 0.07 dried legumes.	0.6 for all vegetables but legumes; 0.45 potatoes; 0.17 dried legumes.	Values are based on USDA Survey, 1966, as cited in USEPA, 1988. Low values represent an urban household, best estimate values represent rural, non-farm households, high represents rural, farm households.	EPA OWRS. Technical Support Document for the Land Application and Distribution and Marketing of Sewage Sludge. August, 1988.
Adult and child consumption rates	Values based on TAS Dietary Database	Values based on TAS Dietary Database	Values based on FDA Study on the Revised Total Diet Food List (Pennington, 1983)	FDA Revised Study values presented in EPA, OWRS, 1987.	TAS Dietary Database. EPA, ECAO. Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge. August, 1987, draft final version.

Table 2.5.H. Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Dietary Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Plant uptake rates	above-ground: 0.02 root: 0.5	above-ground: 0.15 root: 1	Values for whole roots is from the range recommended by Subgroup on Dioxin Update in Terrestrial Plants (memo from Christina Cinalli, June 23, 1989).	Above-ground: High: Young, 1983 Best: recommendation of subgroup on Dioxin Uptake in Plants (6/23/89) memo). Roots: Subgroup on Dioxin Uptake in Terrestrial Plants (6/23/89 memo).
Fraction of vegetables from home garden	0.6 for all vegetables but legumes; 0.45 potatoes; 0.17 dried legumes.	0.6 for all vegetables but legumes; 0.45 potatoes; 0.17 dried legumes.	Values are based on USDA Survey, 1966, as cited in USEPA, 1988. Values represent rural, farm households.	EPA OWRS. Technical Support Document for the Land Application and Distribution and Marketing of Sewage Sludge. August, 1988.
Adult and child consumption rates	Values based on FDA Study on the Revised Total Diet Food List (Pennington 1983)	Values based on FDA Study on the Revised Total Diet Food List (Pennington, 1983)	FDA Revised Study values presented in EPA, OWRS, 1987.	EPA, ECAO. Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge. August, 1987, draft final version.

high estimate is based on Young (1983). For the "best" estimate of MEI exposure, a value of 2 percent is used, while 15% percent is used for the "high risk" MEI exposure estimate.

In the typical exposure analysis, root crops are assumed to take up 50% of the TCDD and TCDF in the soil, with low and high values of 1% to 100% respectively. The "best" estimate MEI analysis uses a value of 50%, and the "high risk" MEI estimate uses 100%. The range of values for these crops was based on the recommendation of the Subgroup on TCDD Uptake in Terrestrial Plants (EPA, 1989d). The Subgroup reviewed data from Wipf et al. (1982), Facchetti et al. (1986), Cocucci et al. (1979), Briggs et al. (1982) and Sacchi et al. (1986) studies of TCDD, as well as Iwata et al. (1974) and Moza et al (1979) studies of PCBs. The low end of recommended range is one of the higher values reported by Wipf et al. (1982), while the high end of the recommended range is in the range of values reported by Moza et al. (1979) for PCB uptake by carrots. The use of these values assumes that the vegetable is eaten whole; that is, the vegetable is washed but is not peeled before it is eaten.

Data Sources and Model Inputs for Fraction of Vegetables from Home Garden

EPA (1988b) cites a USDA survey (1966) that estimated the fraction of vegetables consumed by a person each day that originates from that person's home garden. The fraction was estimated for rural farm residents, rural nonfarm residents, and for urban dwellers. These values are presented in Table 2.5.I. For the best estimate of typical vegetable consumption from home gardens, this analysis uses the values for rural, nonfarm residents. The fraction for urban dwellers represents the low typical estimate, while the fraction for farm residents represents the high typical and the MEI estimate.

Data Sources and Model Inputs for Adult and Child Daily Food Consumption Rates

This analysis assumes that the quantity and types of food consumed by those who have home gardens is the same as for those who do not have home gardens. This assumption allows the use of the TAS Dietary Database, which provides average U.S. dietary consumption values for various age groups. Table 2.5.J. lists the average dietary consumption quantities for adults and children ages one to six years, in g/kg/day. These values are used in both the "low risk" and "best" typical exposure estimates.

EPA (1987b) presents values for average daily consumption of these crops based on an FDA study on the Revised Total Diet Food List. For all crops assumed to be grown in home gardens, the values for consumption from this source are higher than those from the TAS Dietary Database. These

Table 2.5.I. Fraction of Vegetables Consumed from Home Garden

Vegetable	Rural Farm Resident	Rural, Nonfarm Resident	Urban Resident
Dried legumes	0.17	0.07	0.03
Garden fruits	0.6	0.27	0.05
Fresh corn	0.6	0.27	0.05
leafy vegetables	0.6	0.27	0.05
Nondried legumes	0.6	0.27	0.06
Potatoes	0.45	0.15	0.01
Root vegetables	0.6	0.27	0.05

Source: USDA Survey, 1966, cited in EPA, 1988.

Table 2.5.J. Daily Human Food Consumption for Distribution and Marketing Model (g wet weight per kilogram per day)

	TAS Dietary Database		Re-analysis of FDA data from OWRS	
Vegetable	Adults	Children	Adults	Children
Dried legumes	0.3	0.585	0.425	1.939
Garden fruits	1.117	1.83	1.408	2.77
Fresh corn	0.237	0.547	0.69	2.76
leafy vegetables	0.547	0.58	0.616	0.9708
Nondried legumes	0.3	0.585	0.576	2.734
Potatoes	1.126	2.25	1.616	4.01
Root vegetables	0.248	0.38	0.27	0.6

values are used for the high estimate of typical daily consumption, as well as for the estimate of the MEI's daily consumption rates.

Data Sources and Model Inputs for Calculating Size of the Exposed Population

Table 2.5.F. describes the calculations used to estimate the size of population exposed to distributed and marketed sludge. First, the total tons of sludge to distribution and marketing from each plant engaged in this practice were obtained from the 104-Mill Study. The "best" typical exposure analysis assumes that sludge is applied at a rate of 10 DMT per hectare. Dividing tons by the application rate yields the number of acres covered by the distributed and marketed sludge. Next, the size of the average garden is used to determine the number of households using distributed and marketed sludge. According to the National Garden Survey (1987) the average garden size for combined rural and urban vegetable gardens is 0.016 hectares. Dividing acres covered by sludge by the number of acres per household gives the number of households affected. Finally, the number of persons households is multiplied by the average number of persons per household to obtain the total number of persons affected by distributed and marketed sludge. For the "high risk" scenario, the average rural garden size (0.022 hectares) and an application rate of 20 DMT are used to determine exposed population.

2.5.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge

Direct ingestion of soil can occur when sludge is applied to sites where people live. To model the risks from the direct ingestion of sludge contaminated with TCDD and TCDF, this analysis adapts a model developed by Hawley (1985) which accounts for differences in exposure to indoor and outdoor concentrations of soil contaminants. Children ingest far more soil on average than adults; however, adults may also inadvertently ingest soil that adheres to food or cigarettes.

Description of Calculations

The calculation of risks from direct ingest is straightforward. First, the soil concentrations outdoors and the dust concentration indoors are estimated. The outdoor contaminant concentration is multiplied by the quantity of dirt consumed outdoors, while the indoor contaminant concentration is multiplied by the quantity of indoor dust ingested daily. Risk is estimated based on the daily quantity of soil and dust ingested, the gastrointestinal absorption of TCDD and TCDF from soil, and the slope factor of TCDD and TCDF.

Description of Calculations for Estimating Exposure

The concentrations of TCDD and TCDF in outdoor soil are estimated as described in Appendix A. To obtain an estimate of indoor dust contaminant concentrations, the following calculation is performed:

$$C_{in} = C_o F$$

where :

C_{in} = concentration of contaminant in indoor dust, mg/kg
C_o = concentration of contaminant in outdoor soil, mg/kg
F = ratio of the contaminant concentration in indoor dust to the contaminant concentration in outdoor soil

Once the indoor dust and outdoor soil contaminant concentrations are computed, the daily dose of contaminant is calculated for persons in three age groups: young children (ages 1-6), older children (ages 7-11), and adults (ages 12 and older). The daily dose is calculated as:

$$DOSE_g = [(C_o \; DC_g \; F_{g,out}) + (C_{in} \; DC_g \; F_{g,in})] \; AB_g / BW_g$$

where:

AB_{gi} = systemic absorption rate from gastrointestinal tract (expressed as a fraction)
BW_g = body weight of individual in age group g
C_o = concentration of contaminant in soil, mg/kg
C_{in} = concentration of contaminant in indoor dust, mg/kg
DC_g = daily soil ingestion rate for individual in age group g, g/day
$DOSE_g$ = daily dose to individual in age group g, mg/kg/day
$F_{g,in}$ = fraction of ingested soil from indoor sources, adult
$F_{g,out}$ = fraction of ingested soil from outdoor sources, older child

First, for each age group, the concentration of TCDD or TCDF in outdoor soil is multiplied by total quantity of soil ingested each day and by the fraction of ingested soil from outdoor sources for that age group. The same calculations are performed for indoor dust ingestion. The total daily quantity of ingested soil-bound TCDD or TCDF is the sum of the indoor and outdoor quantities ingested. The model then adjusts the total quantity of ingested soil-bound TCDD or TCDF by the fraction absorbed into the system through the gastrointestinal tract, and divides by the body weight of an individual in that age group to obtain an average daily dose in mg/kg/day for that age group.

The weighted average daily dose of contaminant over an individual's lifetime is calculated as the sum of the daily doses for each age group weighted by the fraction of the individual's lifespan spent as a member of that age group, as described in the following calculation:

$$DOSE_{avg} = \Sigma F_g DOSE_g$$

where:

$DOSE_{avg}$ = average daily dose over lifetime, mg/kg/day

$DOSE_g$ = daily dose for individual in age group g, mg/kg/day

F_g = fraction of an individual's lifetime spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with information about the slope factor of TCDD and TCDF to obtain an estimate of lifetime risk from direct ingestion exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg} \; q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day

IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF

q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the individual risk and dividing by the average person's lifespan, as described in the following equation:

$$PC = IC \; POP / LS$$

where:

LS = average lifespan of an individual = 70 years

PC = population risk, cancer cases per year

POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs Used to Estimate Exposure through Direct Ingestion of Sludge

The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.5.K. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.5.L. The best MEI exposure estimate is derived using by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for Soil Concentrations

The methods for deriving the soil concentrations in home gardens where composted sludge is applied are presented in Appendix A. The resulting average soil concentrations over 70 years are displayed in Table 2.5.A. Sludge concentrations were obtained from the 104-Mill Study for plants distributing and marketing sludge.

Data Sources and Model Inputs for Soil Ingestion Rates

To be consistent with other EPA program offices, this analysis uses the soil ingestion rates found in the memo "Interim Final Guidance for Soil Ingestion Rates" (EPA, 1989a). This interim final guidance memorandum gives a suggested range of soil ingestion rates for children of 0.1 to 0.2 grams per day, with a maximum of 0.8 grams per day. The guidance memorandum based the suggested soil ingestion range for children on studies by Binder et al. (1986) and Clausing (1987); both of these groups of researchers studied soil ingestion in children with the use of tracer elements, such as aluminum, silicon, and titanium. The guidance memorandum suggests the use of 0.2 g/day as a best estimate of daily soil ingestion for children. The typical exposure analysis follows the guidance memorandum for young children and uses the range of values suggested, but uses an estimate of 0.1 grams/dy as a best estimate for older children. The MEI analysis uses an ingestion rate of 0.8 grams per day for children, as suggested by the guidance memorandum.

Table 2.5.K. Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Soil Ingestion Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Amount soil ingested, g/day, child	0.1	0.2	0.2	0.1 to 0.2 given by OSWER as the range of "average values" for soil ingestion for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day, older child	0.1	0.1	0.2	0.1 to 0.2 given by OSWER as the range of "average values" for children; however, we used the lower end of this range, 0.1 g/d, as our best estimate for older children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day adult	0.001	0.02	0.1	0.001 to 0.1 given by OSWER as the range of values for adults; OSW suggested use of 0.02 as best estimate value.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Percent of daily ingestion from outdoors, child	0.545	0.545	0.875	Table 4-1 from EPA, 1988 shows summary of Hawley (1985) analysis of soil ingestion. The values presented in this table were converted to percentages. The high value is taken from value for older children.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Percent of daily ingestion from outdoors, older child	0.545	0.875	0.93	Percentage derived from Table 4-1, EPA, 1988. Low value is taken from estimate for younger children, high value from estimate for adults.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)
Percent of daily ingestion from outdoors, adult	0.875	0.93	1.0	Percentage derived from Table 4-1, EPA, 1988. Low value is taken from estimate for older children, high value is maximum percentage possible.	EPA, "Estimating Exposures to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group, 1988 (Draft)

Table 2.5.K. (cont.) Assumptions and Parameter Values for a Typical Individual - Distribution and Marketing: Soil Ingestion Pathway

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Amount of soil ingested from sludge-amended land	0.01	0.10	1.0	Value of 10% was used in evaluation of reuse of municipal sewage sludge. Low and high values arbitrary.	EPA, OWRS, "Human Health Risk Assessment for Municipal Sludge Disposal; Benefits of Alternative Regulatory Options," 1989.
GI absorption rate for soil	0.20	0.45	0.55	Low value used as estimate in "Estimating Exposures to 2,3,7,8-TCDD;" best estimate and high values from range suggested by Bioavailability Workgroup, based on review of studies.	Low: Schaum, 1984 Best, high: "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA.
Soil concentration indoors as function of outdoor concentration	indoor = 75% outdoor	indoor = 80% outdoor	indoor = 85% outdoor		Hawley, 1985

Table 2.5.L. Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Soil Ingestion Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Amount soil ingested, g/day, child	0.8	0.8	Highest estimate for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day, older child	0.8	0.8	Highest estimate for children.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Amount soil ingested, g/day adult	0.1	0.1	Highest estimate for adults.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Fraction of daily ingestion from outdoors, child	1.0	1.0	Assumes all soil from outdoors, where contaminant concentration is higher.	
Fraction of daily ingestion from outdoors, older child	1.0	1.0	Assumes all soil from outdoors, where contaminant concentration is higher.	
Fraction of daily ingestion from outdoors, adult	1.0	1.0	Assumes all soil from outdoors, where contaminant concentration is higher.	

Table 2.5.L. (cont.) Assumptions and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Soil Ingestion Pathway

Input parameter	Best estimate	High	Notes/explanation	Reference
Amount of soil ingested from sludge-amended land	1.0	1.0	Assumes all soil ingested originates from contaminated area.	
GI absorption rate for soil	0.70	0.70	Value from range suggested by Bioavailability Workgroup, based on review of studies.	From: "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA.
Soil concentration indoors as function of outdoor concentration	Indoor = 80% outdoor	Indoor = 85% outdoor		Hawley, 1985

The OSW guidance memorandum gives a range for adult soil ingestion of 0.001 to 0.1 grams per day, based on work by Calabrese et al. (1987), as cited in the OHEA Draft Exposure Factors Handbook (May 1988). In accordance with OSW policy, the typical exposure analysis uses 0.02 grams per day as the best estimate of daily soil ingestion by adults, while using 0.001 and 0.1 to represent the low and high estimates. The most exposed adult is assumed to ingest 0.1 grams per day.

Data Sources and Model Inputs for Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

This analysis assumes that the concentration of TCDD and TCDF in indoor dust is related to the concentration of TCDD and TCDF in outdoor soil. Values for this parameter are derived from Hawley (1985), who assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The typical and MEI exposure analyses use 80% for a "best" estimate, and 85% for a "high risk" estimate. The typical exposure analysis uses a value of 75% for the "low risk" estimate.

Data Sources and Model Inputs for Fraction of Soil Ingested from Outdoor and Indoor Sources

The fraction of soil ingested indoors and outdoors is multiplied by the total daily ingestion rates used by EPA (1989a) to derive the quantities of soil ingested indoors and outdoors each day. To obtain a value for this input parameter, this analysis relies on information presented in EPA (1988a). EPA (1988a) report presents a summary of the work of Hawley (1985), who estimated the dust/soil quantities ingested indoors and outdoors from the dermal soil contact rate and from the area of skin that comes in contact with food, cigarettes, or objects mouthed by children. Although the Hawley (1985) estimates of the total grams per day ingested differ slightly from those used in this analysis, the summary of these values presented in EPA (1988a) is used to estimate the relative fraction of total ingested soil from indoor and outdoor sources. For all age groups, a larger fraction of the total daily quantity of soil ingested comes from outdoor sources, due to the larger dermal soil contact rates outdoors that result in larger ingestion rates. Young children have the largest proportion of total soil/dust ingestion from indoor sources. As a person ages, the relative proportion of soil from outdoor sources increases, due to the decline in the amount of dust ingested while indoors.

The typical exposure analysis uses the fractions derived for each age group from Hawley (1985), as presented in EPA (1988a) for the "low risk" and "best" estimate calculations of direct ingestion exposure. The "high risk" typical exposure estimate assumes that the fraction of soil ingested outdoors for young children is the same as the best estimate for older children. Similarly, the "high risk" estimate for older children uses the same value as the "best" estimate for adults. For adults, the high estimate assumes that all of the soil ingested each day is from outdoor sources. In the MEI analysis, the total quantity of soil ingested by the MEI is assumed to originate from outdoor sources, where concentrations are higher.

Data Sources and Model Inputs for Fraction of Ingested Soil from Contaminated Area

The sludge-amended home garden is only one among may potential sources of ingested soil. Soil may be ingested at locations far removed from the contaminated site, such as a playground or an outdoor workplace. The fraction of the total quantity of ingested soil originating from the portion of the yard or farm treated with TCDD- and TCDF-contaminated sludge may be quite small. However, there is no information available regarding what this fraction may be. In the absence of data, the typical analysis assumes that 10% of the total soil ingestion daily is from sludge-amended land; an arbitrary range of 1% to 100% is used to represent the low and high estimates for this model parameter. In the MEI analysis, all of the soil ingested by the MEI is assumed to originate from the sludge-amended area. These assumptions are the same as those used in the analysis of risks from direct soil ingestion from land treated with municipal sewage sludge (EPA, 1989b).

Data Sources and Model Inputs for Absorption through GI Tract

Absorption of TCDD and TCDF through the gastrointestinal tract has been studied using a variety of media. Absorption will be influenced by how tightly TCDD and TCDF bind to the matrix in which it is ingested. Poiger and Schlatter (1980), as cited in Schaum (1984) reported that the gastrointestinal bioavailability from soil in their studies was 20% to 26%. In a recent review of the literature, FDA (1989) discussed an experiment by Bonaccorsi et al. (1984), who found that G.I. bioavailability of TCDD from freshly "spiked" soil was 56-74%. Umbreit et al. (1988) found lower bioavailability from an environmentally contaminated site, demonstrating that aging of the soil affects bioavailability. Furthermore, McConnell et al. (1984) found that environmentally contaminated soil samples were 24-32% as bioavailable as TCDD in a corn oil matrix or a freshly "spiked" soil matrix. As a result, FDA (1989) recently concluded that a reasonable estimate for absorption from ingested soil is in the range of 45-55%. This range is used in the typical exposure analysis for the "best" and "high risk" estimates, while a value of 20% is adopted for the "low risk" estimate. For the MEI, a gastrointestinal absorption rate of 70% is assumed, which is in the high end of the range cited in the FDA literature review.

Data Sources and Model Inputs for Calculating Size of the Exposed Population

Table 2.5.F. describes the calculations used to estimate the size of population exposed to distributed and marketed sludge. First, the total tons of sludge to distribution and marketing from each plant engaged in this practice were obtained from the 104-Mill Study. The "best" typical exposure analysis assumes that sludge is applied at a rate of 10 DMT per hectare. Dividing tons by the application rate yields the number of acres covered by the distributed and marketed sludge. Next, the size of the average garden is used to determine the number of households using distributed and marketed sludge. According to the National Garden Survey (1987) the average garden size for combined rural and urban vegetable gardens is 0.016 hectares. Dividing acres covered by sludge by the number of acres per household gives the number of households affected. Finally, the number of persons households is multiplied by the average number of persons per household to obtain the total number of persons affected by distributed and marketed sludge. For the "high risk" typical exposure scenario, the average rural garden size (0.022 hectares) and an application rate of 20 DMT are used to determine exposed population.

2.5.4 Estimates of Exposures and Risks from Inhalation of Sludge-Contaminated Particulates

TCDD and TCDF adhering to soil particles can become suspended in the air near a site treated with sludge. Transport downwind will dilute the concentration of particles from a treated area; these particles will also redeposit on surfaces. Residents using composted pulp and paper mill sludge on their home gardens may be exposed to TCDD or TCDF by inhaling these particles. This section describes the methods used to estimate the emissions of particles from a treated site and the subsequent human exposure to these emissions. This analysis only considers exposure to inhaled particulates for residents onsite.

To estimate the suspended particulate concentration at treated sites, the methodology presented in Estimating Exposures to 2,3,7,8-TCDD (EPA, 1988a) is used for estimating emissions due to wind erosion. Although other models for emissions from intermittent, short-term sources, such as spreading operations and vehicular traffic, were also presented, the model for emissions from wind erosion was chosen since the analysis focusses on average exposures over the long-term. EPA (1988a) describes the assumptions underlying the model as follows: "This method assumes that the uncrusted contaminated surface is exposed to the wind and consists of finely divided particles. This creates a condition defined ... as an "unlimited reservoir" and results in maximum wind-caused dust emissions." (p.66). The model incorporates information on wind speed and percent vegetation cover to estimate the flux of small particles (i.e., less that 10 um) from an area of land. Soil amended with paper mill sludge may not have the characteristics assumed by the model; to the extent that the surface of a sludge-amended site consists of crusted, coarser particles, the model is likely to overestimate emissions.

To obtain particulate concentration, the calculated emission rate is used as input to a box model of atmospheric mixing. The box model ignores any atmospheric dispersion downwind, and is only appropriate for estimating onsite concentrations. The model uses wind speed, size of the site and the mixing height to yield an onsite particulate concentration (EPA, 1988a, Equation 4-7).

As an alternative approach to estimating onsite particulate concentration, the model described by Hawley (1985) is also applied; this model uses measured values of total suspended particles adjusted by the fraction of particles assumed to be derived from local (contaminated) soils to derive onsite concentrations of contaminated particles.

The calculation of risks from inhalation of particles requires several steps. First, the emissions of particles from the treated area is estimated. Next, the indoor and outdoor concentrations of particles onsite are calculated. The concentrations are combined with information about the length of time spent indoors and outdoors, respiratory rate, and the slope factor of TCDD and TCDF to yield the estimated cancer risks.

Description of Calculations Used to Estimate the Concentration of TCDD and TCDF in Particulates

The first step in this calculation is to estimate the emissions of particulates from the treated area as follows:

$$E = 0.036\,(1-V)(Um/Ut)^3\ F(x)$$

where:

E = emission rate, g/m^2 hr
V = fraction vegetative cover
Um = windspeed, m/s
Ut = threshold wind speed (wind velocity at height of 7 meters above the ground needed to initiate erosion)
F(x) = function specific to the model, described in EPA (1988a), where F(x) is estimated by f[illegible] calculating $x = 0.886\,(Ut/Um)$

This equation gives the flux of dust particles from the surface is a function of 1) the vegetative covering of the surface and 2) the cube of the ratio of the windspeed to the threshold wind velocity (the velocity required to initiate erosion). F(x) is a function that is specific to this model. The value of x is calculated as a function of the ratio of threshold wind speed to the wind speed. Once the value of x is calculated, F(x) can be determined by reading the value from the graph of the function presented in EPA, OAQPS (1985, as cited in EPA, 1988a).

To convert the dust flux to a contaminant emission rate, the following formula is used:

$$Q = C_s EA \text{ (1 hour/3,600 seconds)}$$

where:

Q = contaminant emission rate in mg/s
C_s = contaminant concentration in the soil, mg/g
E = flux, g/m^2 hr
A = area of the treated site, m^2

The next step is to estimate the concentrations of particulates on the land-treatment site. Both outdoor concentrations and indoor concentrations must be calculated. The outdoor concentration are derived as follows:

$$C_o = Q/\ (L\ MH\ V)$$

where:

C_o = contaminant concentration in suspended particles onsite outdoors, mg/m^3
Q = emissions in mg/sec
L = length of one side of the treated area, m
MH = mixing height (assumed to be 1.5 meters)
V = wind speed at mixing height, m/s, assumed to be 2.2 m/s

An alternative method of calculating outdoor contaminant particulate concentrations is to adjust the measured TSP concentration at the site by the fraction believed to originate from local (contaminated) soils (Hawley, 1985). This method is described by the following equation:

$$C_o = TSP\ FL\ C_s$$

where:

C_o = concentration of suspended particles outdoors originating from sludge-amended land, mg/m^3

C_s = concentration of contaminant in soil, mg/kg

FL = fraction of total suspended particles assumed to originate from local (contaminated) sources

TSP = measured total suspended particle concentration, mg/m^3

Regardless of the method used to estimate outdoor contaminant particle concentrations, the indoor concentrations are derived using the following equation:

$$C_{in} = C_o \, R \, F$$

where:

C_{in} = indoor contaminant concentration, ng/m^3

C_o = outdoor particulate concentration, ng/m^3

R = ratio of indoor particulate concentration to outdoor particulate concentration

F = ratio of the concentration in indoor dust to the concentration in outdoor soil

First, the indoor suspended particle concentration is derived by applying the ratio of suspended particulate concentration indoors to the suspended particulate concentration outdoors. Next, since only a portion of indoor dust is assumed to originate from outdoor sources (the rest is derived from smoking, cooking, etc.) the contaminant concentration in indoor dust is adjusted by a fraction representing the ratio of indoor dust contaminant concentration to the outdoor soil contaminant concentration.

Description of Calculations Used to Estimate Human Exposure to Particulates

Once the concentration of contaminants in particulates is estimated, human exposure to contaminated particulates can be estimated. In the "high risk" typical exposure scenario, and for the "high risk" MEI analysis, the particulate concentration was estimated based on total particulates. When calculating exposure from this estimate of particulate concentration, the first step is to determine the concentration of particles that are respirable. The respirable concentration is estimated as:

$$RC_o = C_o \, FR$$

$$RC_{in} = C_{in} \, FR$$

where:

C_o = concentration of TCDD or TCDF in suspended particles outdoors, mg/m^3
C_{in} = concentration of TCDD or TCDF in suspended particles indoors, mg/m^3
FR = fraction of suspended particles that are respirable
RC_o = respirable particulate concentration outdoors, mg/m^3
RC_{in} = respirable particulate concentration indoors, mg/m^3

In the "low risk" and "best estimate" typical exposure scenarios, and for the "best" estimate MEI analysis, the EPA (1988a) method is used to estimate emissions of contaminant adhering to respirable particles (that is, all of the emissions are assumed to be respirable). Therefore, for these scenarios, no adjustment is needed.

The next step in the calculation of human exposure to TCDD and TCDF through the inhalation of particulates is the estimation of the daily dose. The daily dose is calculated for three age groups: young children (ages 1-6), older children (ages 7-11), and adults (ages 12 and older).

$$DOSE_{o,g} = [(RC_o \, D_l \, AB_l \, H_{o,g}) + (RC_o \, D_{gi} \, AB_{gi} \, H_{o,g})] \, V_g / BW_g$$
$$DOSE_{i,g} = [(RC_{in} \, D_l \, AB_l \, H_{i,g}) + (RC_{in} \, D_{gi} \, AB_{gi} \, H_{i,g})] \, V_g / BW_g$$

where:

AB_l = systemic absorption rate through the lung
AB_{gi} = systemic absorption rate through the gastrointestinal tract
BW_g = body weight of individual in age group g
D_l = fraction of respired particles retained by the lung
D_{gi} = fraction of respired particles swallowed (fraction of particles to gastrointestinal tract)
$DOSE_{o,g}$ = dose to individual in age group g, outdoors, mg/kg/day
$DOSE_{i,g}$ = dose to individual in age group g, indoors, mg/kg/day
$H_{i,g}$ = hours spent indoors for individual in age group g
$H_{o,g}$ = hours spent outdoors for individual in age group g
V_g = weighted average ventilation rate for individual in age group g, m^3/day

In this equation, the concentration of the contaminant adhering to particles is multiplied by the volume of air inhaled each day and by the fraction of the day spent outdoors. Similarly, the quantity of particulates inhaled indoors each day is the product of the indoor respirable concentration, the volume of air inhaled each day, and the fraction of the day spent indoors. The total quantity of particles inhaled each day is then partitioned between the lung and the gastrointestinal tract. A gastrointestinal absorption fraction is then applied to the portion swallowed, while a respiratory absorption fraction is applied to the portion remaining in the lung.

A weighted average dose for an individual over the entire lifetime can be derived by weighting the daily dose received during each age interval by the fraction of the individual's lifespan spent in that age group. This calculation is described in the following equation:

$$DOSE_{avg} = \Sigma\,(DOSE_{o,g} + DOSE_{i,g})\,F_g$$

where:

$DOSE_{avg}$ = weighted average daily dose over lifetime, mg/kg/day
$DOSE_{o,g}$ = dose to individual in age group g, outdoors, mg/kg/day
$DOSE_{i,g}$ = dose to individual in age group g, indoors, mg/kg/day
F_g = fraction of lifespan spent in age group g

Description of Cancer Risk Calculations

Once the daily dose estimate is obtained, it is combined with information about the slope factor of TCDD and TCDF to obtain an estimate of lifetime risk from particulate inhalation exposure to these contaminants. The calculation of individual risk is:

$$IC = DOSE_{avg}\ q_1^*$$

where:

$DOSE_{avg}$ = weighted average daily dose for an individual, mg/kg/day
IC = individual cancer risk over lifetime from $DOSE_{avg}$ of TCDD or TCDF
q_1^* = incremental lifetime risk per mg/kg/day dose of TCDD or TCDF

Individual cancer risk for a typical exposed individual is converted to annual total population risk (in cases per year) by multiplying the number of persons exposed by the typical individual risk and dividing by the average person's lifespan, as described in the following equation:

PC = IC POP / LS

where:

LS = average lifespan of an individual = 70 years

PC = population risk, cancer cases per year

POP = population exposed to $DOSE_{avg}$

Data Sources and Model Inputs for Estimating Exposure through the Inhalation of Particles

The values used for each model input for "low risk," "best" and "high risk" typical exposure estimates are summarized in Table 2.5.M. The values used to derive the MEI "best" and "high risk" exposures are found in Table 2.5.N. The best MEI exposure estimate is derived using by combining estimates of behavioral input parameters with the best estimates of physical/chemical properties of TCDD and TCDF. The "high risk" estimate of MEI exposure uses the same behavioral inputs, but combines them with the high estimates of physical and chemical parameters of TCDD and TCDF.

The following sections describe each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Where parameter input values differ for the "best" and "high risk" MEI exposure estimates, these differences are discussed. For those behavioral input parameters that do not vary between the "best" and "high risk" MEI calculations, a single value for the MEI analysis is discussed.

Data Sources and Model Inputs for the Wind Erosion Flux Calculation

For the "low risk" and "best" typical exposure analyses, and for the MEI "best" estimate, the analysis follows the calculations of EPA (1988a) to calculate wind erosion, and uses many of the input parameters used in the sample calculations in that document. These inputs are briefly described below.

Vegetative cover is assumed to be 50% for the home gardens, since these sites are used for growing plants; the gardens are assumed to be bare for about half of the year, and covered with crops for one-half of the year. For the "low risk" emissions estimate, 90% vegetative cover is assumed.

Mean annual windspeed is 4 m/s. This is the average windspeed at a height of 10 meters for 60 major cities in the United States (EPA 1988a).

The threshold wind speed can be derived if the roughness height and the threshold friction velocity of the surface are known. EPA (1985, as cited in EPA 1988a) describes the ratio of threshold

Table 2.5.M. Assumption and Parameter Values for a Typical Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11 assuming 90% vegetative cover	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Low: calculated using Eq. 6-11 from EPA 1988, assuming 90% vegetation Best estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation High: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.70	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Percent TSP respirable	NA	NA	0.90	Our low and best estimates for emissions are from Eq. 6-11 (EPA, 1988), which gives estimates of small (<10 um) particle emissions. All of these particles are assumed to be respired. The value given here applies only to TSP, which consists of large and small particles (i.e., this value applies only to our high estimate of emissions).	Hawley, 1985
Fraction of TSP to lung	1/6 of respired particles	1/3 of respired particles	1/3 of respired particles	Best and high: one-third of particles found in lungs Low: after 24 hours half of that amount is swallowed.	Schaum, 1984 (citing ICRP, 1968)
Fraction of TSP to GI tract	2/3 of respired particles	2/3 of respired particles	5/6 of respired particles	Low and best: 2/3 initially in G.I. High: one-half of amount in lungs is swallowed within 24 hours.	Schaum, 1984 (citing ICRP, 1968)
Absorption rate, lung		1.0		Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 2.5.M. (cont.) Assumption and Parameter Values for a Typical Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Absorption rate, GI Ingested	0.20	0.45	0.55	Low from Schaum citing Polger and Schlatter study (1980). Best and high from Bioavailability Workgroup review of studies.	Schaum, 1984 "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo from Ivan Boyer, FDA.
Hours per day and number of days spent outdoors, adult	8 hrs/day 21 days	8 hrs/day 40 days	12 hrs/day 130 days	Low: assumes adult works 1 day per wk for 5 months outdoors, 8 hrs/day Best: assumes adult works 2 days per wk, 5 months/yr, 8 hr/day High: 6 months, 5 days/wk, 12 hrs/day.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	8 hrs/day 130 days	8 hrs/day 130 days	12 hrs/day 182 days	Low and best: assumes child plays outdoors 8 hrs/day, May-October, 5 days per wk High: assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	5 hrs/day 152 days	5 hrs/day 152 days	12 hrs/day 152 days	Low and best: assumes child plays outdoors an average of 5 hrs/day, May-September High: assumes 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult: attic, living space	12 hrs/yr in attic; 12 hrs/day, 365 days in living space	12 hrs/yr, in attic; 16 hrs/day, 365 days in living space	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic Low: 12 hrs/day, 365 days in living space Best: 16 hrs/day, 365 days in living space High: 12 hrs/day in living space for 130 days in summer months plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 2.5.M. (cont.) Assumption and Parameter Values for a Typical Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	12 hrs/day 182 days, plus 24 hrs/day, 182 days	16 hrs/day, 130 days, plus 24 hrs/day, 235 days	16 hrs/day 130 days, plus 24 hrs/day 235 days	Low: assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day Best and high: assumes indoors 16 hrs/day, 5 days/wk during May-October, indoors 24 hrs/day for remainder of days. (Note: Low estimate is coupled with high estimate for outdoors.)	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	12 hrs/day 152 days plus 24 hrs/day for 213 days	16 hrs/day for 365 days	16 hrs/day for 365 days	Low: assumes child is indoors 12 hrs/day, 5 months, 7 days/wk Best and high: assumes child is indoors an average 16 hrs/day (Note: Low estimate for indoors is coupled with high estimate for outdoors.)	Adopted from Hawley, 1985
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 75% outdoor	Indoor = 80% outdoor	Indoor = 100% outdoor	Low and best: From Hawley, 1985 High estimate is maximum value possible.	Hawley, 1985

Table 2.5.N. Assumption and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Best estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation High: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Percent TSP respirable	NA	0.90	The value given here applies only to TSP, which consists of large and small particles (i.e., this value applies only to the high estimate of emissions).	Hawley, 1985
Fraction of TSP inhaled to lung	1.0	1.0	All particles are assumed to be absorbed through the lungs.	Schaum, 1984 (citing ICRP, 1968)
Fraction of TSP inhaled to GI tract	0	0	All particles are assumed to be absorbed through the lungs.	Schaum, 1984 (citing ICRP, 1968)
Absorption rate, lung	1.0	1.0	Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 2.5.N. Assumption and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Absorption rate, GI Ingested	NA	NA	All particles are absorbed through lung.	
Hours per day and number of days spent outdoors, adult	12 hrs/day 130 days	12 hrs/day 130 days	Assumes adult works 6 months, 5 days/wk, 12 hrs/day outdoors.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	12 hrs/day 182 days	12 hrs/day 182 days	Assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	12 hrs/day 152 days	12 hrs/day 152 days	Assumes child is outdoors 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult: attic, living space	12 hrs/yr, in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic; 12 hrs/day in living space for 130 days in summer month plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 2.5.N. Assumption and Parameter Values for a Most Exposed Individual - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Best estimate	High	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	12 hrs/day, 182 days, plus 24 hrs/day, 182 days	12 hrs/day 182 days, plus 24 hrs/day 182 days	Assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	12 hrs/day 152 days plus 24 hrs/day for 213 days	12 hrs/day 152 days plus 24 hrs/day for 213 days	Assumes child is indoors 12 hrs/day.	Adopted from Hawley, 1985
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 80% outdoor	Indoor = 100% outdoor	Best: From Hawley, 1985 High estimate is maximum value possible.	Hawley, 1985

wind speed to friction velocity as a function of roughness height. The threshold friction velocity for unlimited reservoir surfaces is less than 75 cm/s (EPA, 1988a). Based on this information, EPA (1988a) adopted a value of 50 cm/s for this type of surface. The present analysis also uses this value for threshold friction velocity on sludge-treated land. For the roughness height of a treated home garden, a value of 2 cm is used, which corresponds to a field with grass cover. The ratio of threshold wind speed to threshold friction velocity for a roughness height is derived from tables provided in EPA (1985), as cited in EPA (1988a). For a roughness height of 2 cm, the ratio is 15. To obtain the threshold wind speed, this ratio is multiplied by 50 cm/s, the assumed value for the threshold friction velocity. The resulting value is 7.5 m/s.

The value for the function F(x) can be obtained from a graph of the function found in EPA (1985), as cited in EPA (1988a). First, the value of x must be calculated. For a site with a threshold wind speed of 7.5 m/s, the estimate is 0.886 x [(7.5 m/s)/(4 m/s)], or 1.66. From the graph provided in EPA (1985), cited by EPA (1988a), the value of F(x) for x = 1.66 is 0.65.

Data Sources and Inputs for TSP Concentrations

As an alternative to the wind erosion dust flux calculation, the method used by Hawley (1985) is also used in this analysis for the "high risk" typical and "high risk" MEI exposure estimates, since the emissions estimate derived by this method is higher than the result using the wind erosion dust flux equation. This method bases the estimate of particulate concentrations on measured values of total suspended particles (TSP). The annual geometric mean values for suspended particle concentrations for SMSAs of between 500,000 and 1 million people were obtained from National Air Quality Trends Report, 1982 (EPA, 1984). The average value for these areas is 64 ug/m^3. This value is similar to the value used by Hawley of 70 ug/m^3. This value is then adjusted by the percent of suspended particles derived from local soils, assumed to be 50 percent (Hawley, 1985).

Data Sources and Model Inputs for Soil Concentrations of TCDD and TCDF

The estimated soil concentrations for home gardens using composted sludge from plants that distribute and market sludge are displayed in Table 2.5.A. The methods used to derive these concentrations is discussed in detail in Appendix A.

Data Sources and Model Inputs for Deriving Indoor Airborne Particle Concentration as a Function Outdoor Particulate Concentration

Hawley (1985) compared several studies that investigated the relationship between indoor particle concentrations and outdoor particle concentrations. Whitby et al. (1957), as cited by Hawley (1985), found that, for the City of Niagara Falls, New York, the indoor suspended particulate concentration was 65 ug/m^3 and the outdoor particulate matter concentration was 93 ug/m^3. This yields an indoor to outdoor ratio of approximately 0.70. Sterling and Kobayashi (1977), also cited in Hawley (1985), found that this ratio ranged from 0.77 to 0.85. The value 0.75 is used as the "best" estimate of this ratio in the typical analysis, while 0.70 and 0.85 are used as the "low risk" and "high risk" estimates, respectively. The MEI analysis uses a value of 0.75 for the "best" estimate of this parameter and 0.85 as the "high risk" estimate.

Data Sources and Model Inputs for Deriving Indoor Dust Contaminant Concentration as a Function of Outdoor Soil Contaminant Concentration

Roberts et al.(1977), as discussed by Hawley (1985), studied the relationship between lead concentrations indoors and outdoors near a lead smelter, and found that the mean concentration of the lead in household dust was 75% the concentration of lead in the outdoor soil. For his own analysis, Hawley (1985) assumed that indoor contaminant concentrations in dust were 80% of the contaminant concentrations in outdoor soil. The typical exposure and MEI exposure analyses use a value of 80% for the "best" estimate and a value of 100% for the "high risk" estimate. The "low risk" typical exposure uses a value of 75% for this input parameter.

Data Sources and Model Inputs for Estimating the Percent of Particulates that are Respirable

Deposition in the lung depends on the size of the particle. The "low risk" and "best" typical exposure analysis and the MEI "best" estimate use a method of estimating emissions of particles less than 10 um in diameter to derive estimates of the concentration of suspended particles. Schaum (1984), presenting data from ICRP (1968), states that almost all particles less than 10 um are respirable. Therefore, for these estimates, all of the particles were assumed to be respirable. In the "high risk" typical and "high risk" MEI scenarios, the concentration of suspended particles is derived from measured values of total suspended particles, a measurement which includes particles of various sizes. Therefore, the fraction of total suspended particles that will be deposited in the lung must be estimated. Hawley (1985) and Schaum (1984) both assumed that 75% of inhaled particles are retained in the body. For particles 0.2 to 20 um, ICRP (1979), as cited in Hawley (1985), indicates that the fraction deposited in the respiratory tract ranges from 60 to 90%. For the "high risk" typical and MEI scenarios, it is assumed that 90% of TSP is respirable.

Data Sources and Model Inputs for Estimating the Fraction of Inhaled Particles Deposited in the Lung and in the Gastrointestinal Tract

Schaum (1984), citing ICRP (1968), discusses the distribution of inhaled particles within the body. Of the particles initially retained by the body, one-third remains in the lower sections of the lung, and two-thirds remain in the upper respiratory tract, where they are swallowed. After twenty-four hours, approximately one-half of the amount originally retained in the lower sections of the lung is swallowed. For the typical exposure analysis "best" estimate and "high risk" scenarios, it is assumed that one-third of particles are retained in the lung for a sufficient length of time for systemic absorption of TCDD and TCDF to occur through the lung. For the "low risk" typical exposure scenario, the analysis assumes that only one-sixth of the particles are retained in the lung for a sufficient length of time for absorption of contaminants through the lung to take place. The rest is swallowed and absorbed through the GI tract (which has a lower systemic absorption rate). In the MEI analysis, it is assumed that all respirable particles are retained long enough in the lung for systemic absorption through the lung to occur (that is, all of the contaminants adhering to respired particles that are absorbed are absorbed through the lung).

Data Sources and Model Inputs for Respiration Rate

Respiration rate is used in the model to assess the total daily volume of particles inhaled. For adults, the average respiration rate was calculated by EPA (1985) to be 23 m^3 per day. This value was calculated using data on the ventilation rates during different levels of activity, and the amount of time spent per day engaging in these levels of activity, to obtain a daily total. For children, Hawley states that the ventilation rate of young children engaged in light activity is 7.6 l/min, while the ventilation rate during rest is 2.8 l/min; assuming children spend roughly one-third of their day engaged in light activity and two-thirds at rest, the total ventilation rate is 6.3 m^3 per day. For older children, the ventilation rate is 11.6 l/min during light activity and 4.3 l/min at rest (Hawley, 1985), with a total ventilation rate of 8.4 m^3 per day. These values are used in both the typical and MEI analyses.

Data Sources and Model Inputs for Estimating Absorption through Lung

Little data are available to estimate the systemic absorption of TCDD or TCDF through inhalation. Faced with a lack of information, U.S. EPA (1989c) assumed that TCDD is almost completely absorbed from respirable particles (i.e., those less than 10 um in diameter). The typical and MEI analyses follow this assumption for TCDD and TCDF, and assume 100% absorption through the lung.

Data Sources and Model Inputs for Estimating Absorption through GI Tract

Absorption of TCDD and TCDF through the gastrointestinal tract has been studied using a variety of media. Absorption will be influenced by how tightly TCDD and TCDF bind to the matrix in which it is ingested. Poiger and Schlatter (1980), as cited in Schaum (1984) reported that the bioavailability of TCDD from soil was 20-26%. In a recent review of the literature, FDA (1989) discussed an experiment by Bonaccorsi et al. (1984), who found that availability of TCDD from freshly "spiked" soil was 56-74%. Umbreit et al. (1988) found lower bioavailability from soil from an environmentally contaminated site, demonstrating that aging of the soil affects bioavailability. Furthermore, McConnell et al. (1984) found that environmentally contaminated soil samples were 24-32% as bioavailable as TCDD in a corn oil matrix or a freshly "spiked" soil matrix. As a result, FDA (1989) recently concluded that a reasonable estimate for absorption from ingested soil is in the range of 45-55%. For the typical exposure analysis, this range is used for the best and high estimates, while a value of 20% is adopted for the low estimate. No gastrointestinal absorption of inhaled particles occurs for the MEI,.since all absorption is assumed to occur through the lungs.

Data Sources and Model Inputs for Determining the Fraction of the Day Spent Indoors and Outdoors

In order to estimate exposure duration in indoor and outdoor settings, the methodology developed by Hawley (1985) to estimate the time spent outdoors and indoors by different age groups is adapted. For adults, Hawley also presented values for estimating exposure to dust while cleaning infrequently used spaces, such as attics, that have been incorporated into both the typical and MEI analyses.

Young children have the most exposure to outdoor particulate concentrations. In the "low risk" and "best" typical exposure assessments, these children are assumed to be outdoors 8 hours per day, five days per week from May to October. The remaining time is spent indoors on the site. As a high estimate of typical exposure, it is assumed that young children are outdoors for an average of six hours a day for the entire year, which is the equivalent of twelve hours per day, seven days a week for the six months out of the year. This assumption is also used for the young child in the MEI analysis.

Typical older children are assumed to spend an average of five hours per day from May to September outdoors. This value, used in both the "low risk" and "best" estimates of typical exposure, is the average of time spent outdoors after school on school days and time spent outdoors on weekends and on school vacation days. Older children are assumed to be indoors on the site for sixteen hours per day for the entire year. The remainder of the time is spent at another indoor location, such as school. As a high estimate of typical exposure, older children are assumed to be outdoors an average of 5 hours per day for the entire year, which is the equivalent of 12 hours per day for five months, and to be indoors on the site for the remainder of the time. This assumption is used for the older child in the MEI analysis as well.

The distribution and marketing "best" typical exposure analysis assumes that adults engage in outdoor activities for 8 hours per day, two days a week from May to September. Adults are assumed to spend 16 hours per day indoors at a location near the site all year long. The rest of the time is spent outdoors (two days per week) or in other locations such as the workplace. As a low estimate of typical outdoor exposure duration, it is assumed that adults only spend eight hours per week from May to September engaged in outdoor activities, while spending only 12 hours per day indoors at an indoor location near the contaminated site. For the "high risk" typical estimate, and for the MEI analysis, it is assumed that distributed and marketed sludges go to farms, where an adult (i.e., a farmer) works outdoors 5 days per week, 12 hours per day, for six months, and spends the rest of the time indoors at a location near the site.

While indoors, adults may spent a limited amount of time in an extremely dusty area, such as an attic, where exposure to inhaled dust would be higher than in normal living spaces. Hawley (1985) estimated exposure to dust to be 20 mg during one hour in the attic, and assumed that adults are exposed at this level for twelve hours each year (either one day for 12 hours or one hour for twelve days). The current analysis incorporates these assumptions into both the typical and MEI analyses.

Data Sources and Model Inputs for Calculating Size of the Exposed Population

Table 2.5.F. describes the calculations used to estimate the size of population exposed to distributed and marketed sludge. First, the total tons of sludge to distribution and marketing from each plant engaged in this practice were obtained from the 104-Mill Study. The "best" typical exposure analysis assumes that sludge is applied at a rate of 10 DMT per hectare. Dividing tons by the application rate yields the number of acres covered by the distributed and marketed sludge. Next, the size of the average garden is used to determine the number of households using distributed and marketed sludge. According to the National Garden Survey (1987) the average garden size for combined rural and urban vegetable gardens is 0.016 hectares. Dividing acres covered by sludge by the number of acres per household gives the number of households affected. Finally, the number of persons households is multiplied by the average number of persons per household to obtain the total number of persons affected by distributed and marketed sludge. For the "high risk" typical exposure scenario, the average rural garden size (0.022 hectares) and an application rate of 20 DMT are used to determine exposed population.

2.5.5 Estimates of Exposure and Risks from Inhalation of Vapors

Residents using distributed and marketed sludge may incur risk from the inhalation of volatilized TCDD and TCDF. The methodology for estimating the emissions of TCDD and TCDF vapor at residential sites generally follows methods for estimating volatilization described in EPA (1988a). Because actual locations of the homes using composted sludge are not known, the ISCLT model could not be used to estimate downwind concentrations. As a result, this analysis estimates only exposures to onsite residents, using a box model to obtain the onsite concentrations from the emissions estimates.

The calculation of risks from the inhalation of vaporized TCDD and TCDF requires first the estimation of emissions, then the calculation of indoor and outdoor onsite concentrations. The concentrations are combined with data on time spent indoors and outdoors, respiration rate and slope factor of TCDD and TCDF to obtain the estimated cancer risk from this pathway of exposure.

Methods for Estimating Vapor Emissions

This analysis uses a set of equations from U.S. EPA (1986), and Hwang and Falco (1986) as described in U.S. EPA (1988a), to predict emissions from a home garden. It assumes that emissions from home gardens (in $g/m^2/s$) are described by:

$$N_a = \frac{2D_i E^{4/3} K_{as} C_{so}}{[\pi \alpha T]^{1/2}}$$

where:

$$\alpha = \frac{D_i E^{4/3}}{E + p_s(1-E)/K_{as}}$$

$$K_{as} = 41\ H_c/K_D$$

and:

D_i = the molecular diffusivity of contaminant vapor in air (cm/second)

C_s = the contaminant concentration in the soil (g/g),

E = effective porosity of soil, assumed to be 0.25 (unitless)

H_c = Henry's law constant (atm m^3/mol)

p_s = true density of soil, assumed to be 2.65 g/cm3

K_D = the soil/water partition coefficient (cm^3/g) = (organic carbon/water partition coefficient)(fraction of organic carbon in soil)

K_{as} = the air/soil partition coefficient (mg/cm^3 in air per mg/g in soil)

N_a = rate of emissions from the soil surface (g/m^2/second)

T = duration of exposure (seconds), assumed to be 2.2×10^9 seconds (70 years)

This equation uses information on the partitioning of TCDD and TCDF between soil and air and between water and soil to estimate emissions of TCDD and TCDF vapor per m^2 area. The emissions estimate is then multiplied by the area of the home garden, in m^2, to obtain the total emissions of vapor from the residential site:

$$Q = 1000\ N_a\ A$$

where:

Q = emissions rate for contaminant vapor, mg/s
A = area of home garden, m^2
1000 = conversion from grams to milligrams

The emission rate is then coupled with a box model to obtain the onsite concentrations of vapor. Outdoor vapor concentrations are estimated as:

$$C_o = Q/(L\ MH\ V)$$

where:

C_{out} = concentration of vapor outdoors, mg/m^3
Q = emissions, mg/sec
L = length of one side of the garden, m
MH = mixing height (assumed to be 1.5 meters)
V = wind speed at mixing height, m/s, assumed to be 2.2 m/s

The indoor vapor concentration is derived by applying the ratio of vapor concentration indoors to the vapor concentration outdoors, as described in the following equation:

$$C_{in} = C_o R$$

where:

C_{in} = indoor vapor concentration, ng/m^3
C_{out} = outdoor vapor concentration, ng/m^3
R = ratio of indoor vapor concentration to outdoor vapor concentration

It is assumed that the relationship between vapor concentrations indoors and outdoors is similar to the ratio between indoor and outdoor particulate concentrations (that is, indoor concentrations are approximately 75% of outdoor concentrations with a range from 70-85%).

Once the concentration of contaminant in the air is estimated, the calculation of exposure and risks from the inhalation of vapor then proceeds in the same manner as the exposure and risk from the inhalation of particles, described in section 2.5.4. Table 2.5.M. summarizes key assumptions and input parameters for estimating typical exposure through the vapor and particulate inhalation pathways, while Table 2.5.N. summarizes the MEI analysis inputs. In some cases, the data inputs used for the estimation of exposure and risk are different than those used in section 2.5.4. The data inputs unique to the calculation of risk from the inhalation of vapor are described in following sections.

Data Sources and Model Inputs for Estimating Volatile Emissions

The emissions model requires the soil/water partition coefficient as an input. This partition coefficient is, in turn, based on the fraction of organic carbon in the soil. Therefore, the TCDD and TCDF vapor emissions from sludge applied to home gardens will depend on the organic content of the sludge or the sludge/soil mixture. The higher the f_c value, the lower the volatile emissions, since more of the contaminant will partition to soil rather than air. In this analysis, the "best" estimate and "low risk" typical scenarios assumes that home gardeners soil-incorporate sludge. For these scenarios, it is assumed that the fraction of organic carbon in the sludge-soil mixture is approximately equal to the fraction of organic carbon in the soil alone. A reasonable "best" estimate for f_c for soils is 1%; the "low risk" estimate for this value is 4%, since a higher value of f_c will yield a lower vapor emissions estimate, and hence a lower exposure estimate. For the "high risk" typical and MEI analyses, where top-dressing is practiced, a low value of f_c for sludge is used. NCASI

(1984) reports that the organic carbon content of sludge ranges from 14% to 40%. This analysis uses the low end of this range, 14%, to obtain the "high risk" typical and MEI vapor inhalation exposure estimates, since the lower value of f_c will yield higher vapor emissions, and thus higher exposures.

Data Sources and Model Inputs for Estimating Exposure to TCDD and TCDF Vapor

The data inputs and model sources for the vapor exposure estimate are the same as those described in section 2.5.4., with two exceptions. First, 100 percent of vapor emissions are assumed to be respired. Second, all of the vapor is absorbed through the lung; none is absorbed through the GI tract.

2.5.6 Summary of Results

The best estimates of typical and MEI exposure and health risks from the distribution and marketing of paper mill sludge containing TCDD and TCDF are summarized in Tables 2.5.O. and 2.5.P. The "low risk" and "high risk" typical exposure and risk estimates, as well as the "high risk" MEI exposure and risk estimates, are found in Chapter 4, Uncertainty Analysis. Tables 2.5.O and 2.5.P. show that the pathways of exposure posing the greatest health risk are the direct ingestion and vapor inhalation pathway. The best estimate for typical daily exposure through both the direct ingestion and vapor inhalation pathway is approximately 2×10^{-13} mg/kg/day. The best estimate of typical exposure for the direct ingestion pathway results in a risk of 6×10^{-8}, or approximately 3×10^{-3} cancer cases per year, based on an estimated exposed population of 3,510,000 persons. The best estimate of typical exposure for the vapor inhalation pathway results in a risk of 4×10^{-8}, or approximately 2×10^{-3} cancer cases per year.

Dietary exposures pose the lowest risks. The typical daily exposure estimated for this pathway is 6×10^{-17} mg/kg/day. This exposure leads to an individual average risk of 2×10^{-11}, and an estimated 8×10^{-7} cases per year. Dietary risks are low because plants take up relatively little TCDD and TCDF from the soil.

In general, risks for the "most exposed individual" (MEI) are two to three orders of magnitude higher than the risks for a typical individual. Estimate risks for the MEI are lowest for the particle inhalation and dietary pathways, and are highest for the pathways involving direct human contact with contaminated soil (i.e., the dermal and direct ingestion pathways). The dermal contact pathway results in an incremental lifetime cancer risk for the MEI of 8×10^{-5}, based on an estimated daily exposure of 3×10^{-10} mg/kg/day. The direct ingestion pathway results in an

Table 2.5.0. Best Estimate of Human Exposure from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)	Typical exposure[a] (mg/kg/day)	(% TCDD)
Dermal exposure from contact with soil contaminated by distributed and marketed sludge:	3×10^{-10}	(35)	5×10^{-14}	(38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge:	8×10^{-10}	(35)	2×10^{-13}	(38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge:	3×10^{-12}	(1)	2×10^{-13}	(2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge:	4×10^{-13}	(35)	4×10^{-15}	(38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge:	5×10^{-14}	(35)	6×10^{-17}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 2.5.P. Best Estimate of Human Health Risk from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	8×10^{-5} (35)	1×10^{-8} (38)	3,500,000	7×10^{-4} (38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-4} (35)	6×10^{-8} (38)	3,500,000	3×10^{-3} (38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	8×10^{-7} (1)	4×10^{-8} (2)	3,500,000	2×10^{-3} (2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-7} (35)	1×10^{-9} (38)	3,500,000	5×10^{-5} (38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-8} (35)	2×10^{-11} (38)	3,500,000	8×10^{-7} (38)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

incremental lifetime cancer risk for the MEI of 2×10^{-4}, based on an estimated daily exposure of 8×10^{-10} mg/kg/day.

In all pathways examined in the distribution and marketing scenario, TCDF contributes more to risk than TCDD. This result is due to the fact that TCDF concentrations are, on average, seven times higher than TCDD concentrations in sludges from mills assumed to distribute and market sludge. For the vapor inhalation pathway, TCDF contributes almost all of the risk, because it is more easily volatilized than TCDD.

REFERENCES FOR SECTION 2.5

Consumer Product Safety Commission (1989). "Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Di-benzo-p-dioxins and Dibenzofurans," memorandum dated July 6 from M. Babich.

Food and Drug Administration (1989). "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo dated June 22 from Ivan Boyer.

Hawley, J.K. (1985). Assessment of health risk from exposure to contaminated soil. Risk Analysis 5(4):289-302.

Keenan, R.E., Sauer, M., Lawrence, F., Rand, E., and D. Crawford (1989). "Examination of potential risks from exposure to dioxin in sludge used to reclaim abandoned strip mines." In: The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. D.J. Paustenbach, ed. J. Wiley and Sons, New York, pp. 935-998.

Kimbrough, R., Falk, H. and P. Stehr (1984). Health implications of 2,3,7,8-TCDD contamination of residential soil. J. Tox. Envir. Health 14:47-93.

National Council of the Paper Industry for Air and Stream Improvement (1984). The Land Application and Related Utilization of Pulp and Paper Mill Sludges. Technical Bulletin Number 439, August.

National Council of the Paper Industry for Air and Stream Improvement, Inc (1987). Assessment of Human health Risks Related to Exposure to Dioxin from Land Application of Wastewater Sludge in Maine. June.

National Gardening Survey Association, Inc. (1987). National Gardening Survey, 1986-1987.

National Research Council Canada (1981). Polychlorinated Dibenzo-p-Dioxins: Criteria for Their Effects on the Environment. NRCC Document Number 18574.

Sacchi, G.A., P. Vigano, G. Fortunati, and S.M. Cocucci. (1986). "Accumulation of 2,3,7,8-Tetrachlorodibenzo-p-dioxin from soil and nutrient solution by bean and maize plants". Experientia 42:586-588.

Schaum, J. (1984). Risk analysis of TCDD contaminated soils. U.S. EPA, Office of Health and Environmental Assessment, EPA 600//84-4/031, November.

U.S. Department of Agriculture (1979). "Use of Sewage Sludge Compost for Soil Improvement and Plant Growth," ARM-NE-6, August.

U.S. EPA, Office of Air Quality, Planning and Standards (1984). National Air Quality and Emissions Trends Report, 1982. EPA-450/4-84-002, March.

U.S. EPA (1985). Development of Statistical Distributions or Ranges of Standard Factors Used in Exposure Assessments. EPA/600/8-85/010, August. Prepared by GCA Corp., Chapel Hill, N.C.

U.S. EPA (1987a). "Comparison of Food Consumption Data". Tolerance Assessment Program, Office of Pesticides and Toxic Substances. Washington, D.C.

U.S. EPA (1987b). Office of Health and Environmental Assessment, Evaluation and Criteria Assessment Office. Development of Risk Assessment Methodology for the Land Application and Distribution and Marketing of Municipal Sludge August, final draft version.

U.S. EPA (1988a). Office of Health and Environmental Assessment, Exposure Assessment Group. Estimating Exposure to 2,3,7,8-TCDD. Draft Report March.

U.S. EPA (1988b). Office of Water Regulations and Standards, Technical Support Document for the Land Application and Distribution and Marketing of Sewage Sludge. Draft Report, August.

U.S. EPA (1989a). "Interim Final Guidance for Soil Ingestion Rates." Office of Solid Waste Emergency Response Directive Number 9850.4, January 27 from J. Winston Porter.

U.S. EPA, Office of Water Regulations and Standards (1989b). Human Health Risk Assessment for Municipal Sludge Disposal: Benefits of Alternative Regulatory Options, February.

U.S. EPA (1989c). Health and Environmental Review Division memorandum to Greg Schweer, Office of Toxic Substances, U.S. EPA, on the dioxins in paper products: bioavailability by inhalation, dated June 16 from F.J. DiCarlo.

U.S. EPA (1989d). Memorandum to Dioxin-in-Paper Workgroup, on the bioavailability of dioxins in paper products, dated June 23 from C. Cinalli and Conrad Flessner.

U.S. EPA (1989e). 104-Mill Data Base. Office of Water Regulations and Standards, July 17 version.

U.S. EPA (1989f). Memorandum to Dioxin-in-Paper Workgroup, dated July 21 from C. Cinalli.

Wipf, H.K., E. Homberger, N. Neuner, U.B. Ranalder, W. Vetter, and J.P. Vuilleumier (1982). "TCDD levels in soil and plant samples from the Seveso area." In: Huntiziger, O., R.W. Frei, E. Merian, and F. Pocchiari, editors. Chlorinated Dioxins and Related Compounds: Impact on the Environment, Pergamon Press, New York.

3.0 Estimates of Exposure and Risks to Wildlife from Land Application of Pulp and Paper Sludge

The land application of contaminated sludges to agricultural sites, mine reclamation sites, and silvicultural sites can lead to wildlife exposures to TCDD and TCDF. The exposure may have adverse toxic, teratogenic, or reproductive effects on an individual organism exposed to TCDD or TCDF. The effects on individual organisms may also lead to effects on the overall structure and health of the ecosystem. Wildlife species living on or near the land application site can be exposed to TCDD or TCDF through direct contact with contaminated soil, direct ingestion of soils, ingestion of contaminated plants, ingestion of prey items that have bioconcentrated TCDD or TCDF, or inhalation of TCDD or TCDF vapor or contaminated particulates. Furthermore, wildlife species may also be indirectly affected by land application of sludge, through the runoff of contaminated soil into surface water bodies. Exposure could result from gill contact with suspended sediments, predation on sediment-dwelling organisms, or feeding on sediments directly.

This analysis is limited to the consideration of terrestrial species and predators of terrestrial species. Risks to aquatic organisms and their predators are not assessed but may be important[1]. In particular, risks to sediment-dwelling organisms could be of concern because of the tendency TCDD and TCDF to adsorb to particles. Furthermore, this analysis examines only the dietary and direct ingestion pathways of exposure. These pathways were chosen for assessment because of the potential for significant wildlife exposure through these pathways and because of the availability of data needed to perform the exposure assessment.

Because the methods for predicting the effects of chemicals on ecosystems are not yet well-developed, this analysis estimates only possible effects of TCDD and TCDF on individual organisms and their ability to produce viable offspring. The analysis does not attempt to predict the effects of the pollutants on whole populations of wild species of birds and mammals, or on ecosystems.

Since the completion of this analysis, the Environmental Effects Branch (EEB) of the Office of Toxic Substances updated this assessment with the most recent information available on TCDD and TCDF toxicity and exposure to fish and wildlife. The EEB also performed an evaluation of the terrestrial exposure assessment presented in this report. The EEB update and evaluation are found in Appendix F.

---

[1] Exposure from ingestion of fish contaminated by runoff from the treated area is analyzed for one mammalian species (the river otter). Risks to this mammal were analyzed because it is a threatened species in one state in which sludge is land-applied (Ohio).

3.1 Development of Toxicity Measures to which Wildlife Exposures are Compared

A host of adverse effects to individual animals from TCDD has been well-documented in laboratory studies. Using the results of these studies to estimate effects on wild populations is fraught with difficulties. The route and medium of administration and the duration of exposure to TCDD for laboratory animals usually will differ from that of wild animals. Using these studies to assess effects on wild species assumes that the wild species are as sensitive or more sensitive to TCDD than the laboratory species. Furthermore, in an assessment of the effects of chemicals on wildlife, the impacts on entire populations or ecosystems are of interest. The methodologies for predicting the effects of chemicals on terrestrial wildlife populations and ecosystems, however, are still in development. In the absence of sophisticated predictive methods, measures of effects of chemicals on reproduction are useful indicators of possible effects on the populations of the species in the wild.

This analysis estimates exposures to individual birds and mammals and estimates concentrations in bird eggs. It is beyond the scope of this project to develop a dose-response relationship for the range of possible adverse effects that may result from wildlife exposure to TCDD and TCDF. Instead, estimated exposures are compared to benchmark doses that have been identified as causing adverse effects in laboratory species. Exposure levels approaching or exceeding the selected benchmark suggest that the exposed animal is at risk for experiencing adverse effects. Where possible, doses observed to cause adverse reproductive effects were selected as benchmarks; the exposure of a number of individual members of a species to a dose exceeding such a reproductive effect benchmark may lead to adverse overall population effects.

For birds, the estimated daily dose to adult birds is compared to the dose that had no observable adverse effects in laboratory experiments (the NOAEL). The concentration in bird eggs is compared to the lowest concentration observed in a laboratory that caused observed adverse effects (the LOAEL). For mammals, the dose is compared to the lowest observable dose to cause reproductive effects in laboratory animals. A number of studies on the toxicity of TCDD to laboratory animals are summarized in Table 3.1.A. The studies upon which the LOAELs or NOAELs were based are described below. The discussion that follows also describes the adjustments made to these doses in order to compare them to estimated wildlife exposures.

Development of the NOAEL for Birds

Schwetz et al. (1973, as cited in Keenan, 1986) administered 100 ng/kg body weight/day TCDD in a corn oil/acetone vehicle to 3 day old white leghorn chickens. The researchers

Table 3.1.A. Summary of Studies on the Toxicity of 2,3,7,8-TCDD to Animals

SPECIES	EXPOSURE LEVEL	SYMPTOMS/EFFECTS	REFERENCE
Male Rat	.022 mg/kg body weight single oral dose	LD$_{50}$	Schwetz et al. 1973
Female Rat	.045 mg/kg body weight single oral dose	LD$_{50}$	
Male Guinea Pig	.0006 mg/kg body weight single oral dose	LD$_{50}$	
Mixed Rabbits	.115 mg/kg body weight single oral dose	LD$_{50}$	
	.275 mg/kg body weight single skin absorption dose	LD$_{50}$	
	.04 ug/ml single application to skin	Chloracne	
Chickens	1 mg/kg/day	Positive chick edema bioassays (lesions)	
Guinea Pigs	4 ug/kg single dose	59% decrease in LPL activity in the heart muscle 10 days after dose.	Brewster et al. 1987
Eastern Bluebird	10,000 ppt	LOAEL for eggs	Thiel et al. 1988
Chickens	10^{-10} M Concentration of TCDD	60% reduction in lymphoid cell numbers	Nikolaidis et al. 1988
White Leghorn Chickens	30-65 ppt	LOAEL for eggs	Sullivan et al. 1987
Northern Bobwhite	15 ug/kg body weight single oral dose	LD$_{50}$	Eisler 1986
Ringed Turtle-Dove	810 ug/kg body weight single oral dose	LD$_{50}$	
Mallards	108 mg/kg body weight single oral dose	LD50	
Rhesus Monkeys	.0017 ug/kg body weight daily (7-29 months)	abortion and weight loss	
Pregnant Female Mice	1.0 ug/kg body weight daily	Cleft Palate in young mice	
	.01 ug/kg body weight daily	NOAEL	

Table 3.1.A. (con't) Summary of Studies on the Toxicity of 2,3,7,8-TCDD to Animals

SPECIES	EXPOSURE LEVEL	SYMPTOMS/EFFECTS	REFERENCE
Rats	.125 ug/kg body weight daily	intestinal hemorrhage	
	.03 ug/kg body weight daily	NOAEL	
	.01 - .1 ug/kg body weight daily	carcinomas in liver, pharynx, skin, lung, and thyroid	
	.001 -.0014 ug/kg body weight daily	no increase in tumors	
	15 ug/kg body weight single dose	androgenic deficiencies	
	.01 ug/kg body weight daily	decreased litter size at birth increase stillborns, and reduced survival of young.	
Mice	.03 - .07 ug/kg body weight daily	carcinomas in liver, phalanx, skin, lung, and thyroid	
	.001 -.03 ug/kg body weight daily	no increase in tumors	
Monkeys	.011 ug/kg/day (9.3 months)	generalized toxicity: anemia, hair loss, death. 1 of 2 pregnancies aborted	Kociba and Schwetz 1982
	.0017 ug/kg/day 7-20 months	slight loss of weight and hair. 4 of 7 pregnancies aborted	
	.24 ug/kg three times weekly for 3 weeks of early gestation	severe toxicity (death) 2/2 pregnancies aborted	
	.048 ug/kg three times weekly for 3 weeks of early gestation	Slight toxicity 3/4 pregnancies aborted	
	.0095 ug/kg three times weekly for 3 weeks of early gestation	no toxicity 1/4 pregnancies aborted	
	Control	3/11 pregnancies aborted	

Table 3.1.A. (con't) Summary of Studies on the Toxicity of 2,3,7,8-TCDD to Animals

SPECIES	EXPOSURE LEVEL	SYMPTOMS/EFFECTS	REFERENCE
Bobwhite	167 ppt 5 day/8 day test	LC50	Kenaga and Norris 1983
	3 ppt 18 wk/18 wk test .3 ppt 18 wk/18 wk test	no effect on reproduction	
Mallard	278 ppt 5 day/8 day test	LC10	
Turkey	>259 ppt 11 day/11 day test	EC0	
Chicken	>500 ppt 21 day/21 day test	LC90	
	>200 ppt " "	LC0 reduced feeding and growth	
	>100 ppt " "	LC0	
Rat	200 ug/kg single oral dose	multinucleated cells	Ontario Ministry of the Environment 1988
	.25,1,2,4 ug/kg 26 doses biweekly	chromosomal aberrations	
Mice	1,3 ug/kg/day 10-13 days	cleft palate kidney abnormality	
Rat	.5 ug/kg/day 6-15 days	kidney abnormality	
	.125-16 ug/kg/day 6-15 days	hemorrhage, fetolethality at dose greater than 1 ug/kg/day	
Rats	.1 ug/kg body weight per day	increased mortality, decreased body weight, depressed hematological parameters, etc.	National Research Council Canada 1981
	.01 ug/kg body weight per day	Liver toxicity and focal alveolar hyperplasia, in females increased urinary porphyrins.	
	.001 ug/kg body weight per day	no toxic effects of significance	
	.01 ug/kg body weight per day	significant increase in liver preneoplastic lesions	

Table 3.1.A. (con't) Summary of Studies on the Toxicity of 2,3,7,8-TCDD to Animals

SPECIES	EXPOSURE LEVEL	SYMPTOMS/EFFECTS	REFERENCE
Mice	.01 ug/kg body weight per day	significantly increased numbers of liver tumors	
	.071 ug/kg body weight per day	increase in hepatocellular carcinoma and hepatocellular neoplastic nodules	
Female Mice	.029 ug/kg body weight per day	increased fibrosarcoma, histiocytic lymphoma, thyroid follicular cell adenoma and adrenal cortical adenoma.	

administered this dose for 21 days and found that this dose produced no adverse effects. It is assumed that TCDD is 100% absorbed from the corn oil/acetone vehicle (FDA, 1989). However, it is not expected the absorption of TCDD from food would be the same as the absorption from a corn oil vehicle. Accordingly, the estimated dose to wildlife species from the ingestion of prey items is adjusted by the percent of TCDD assumed to be absorbed from the diet. Values for this percentage are found in a recent review of the literature performed by FDA (FDA, 1989). In addition, the laboratory dose must be converted to an equivalent dose over the length of time that wild species of birds are exposed to TCDD from the sludge applied to the land-treated area. All of the migratory birds in this analysis are assumed to reside in the land-treated area for 6 months (180 days); for these birds, the NOEL is adjusted by a factor of 180/21, or about 9 (Keenan, 1986). In this case the adjusted NOAEL is 100/9 ng/kg/day, or 11 ng/kg/day. The loggerhead shrike is assumed to remain onsite for the entire year. For this species, the NOAEL is adjusted by a factor of 365/21, or about 17. In this case, the adjusted NOAEL is 100/17 ng/kg/day, or 6 ng/kg/day. The toxic equivalency factor for TCDF is 1/10 of TCDD (U.S. EPA, 1989a). Therefore, the NOAEL value used for comparison to doses of TCDF estimated from this analysis are 10 times the NOAEL for TCDD.

Development of the LOAEL for Bird Eggs

Bird eggs can contain TCDD transferred from the mother's body burden of TCDD. Eggs are an important endpoint to consider because of their sensitivity to TCDD. Sullivan et al. (1987) concluded that the LOAEL for chicken embryos is 65 pg/g in the egg (65 ppt), based on a study that found a 2-fold increase in cardiovascular malformations in chicken embryos at an estimated egg concentration of 65 pg/g. Although effects were found at lower concentrations of TCDD, Sullivan et al. (1987) concluded that the evidence for effects at these lower levels was inconclusive. The 65 ppt value is used in this analysis for comparison with predicted egg concentrations for wild species. The toxic equivalency factor for TCDF is 1/10 of TCDD (U.S. EPA, 1989a). Therefore, the LOAEL value used for comparison to doses of TCDF estimated from this analysis are 10 times the LOAEL for TCDD, or 650 ppt.

Development of the LOAEL for Mammals

This analysis compares exposures for small mammals (i.e., mammals less than 1 kg) to the lowest observed adverse reproductive effect level in laboratory rats. Murray et al. (1979), as cited by Kociba and Schwetz (1982) administered rats 100, 10, and 1 ng/kg/day through the diet, and studied the effects on subsequent generations. This analysis compares exposure estimates to the 10 ng/kg/day level, where Murray et al. (1979) found decreased fertility in the f_1 and f_2 generations. For larger mammals, the expected dose for wild species is compared to the lowest dose observed to produce adverse reproductive effects in rhesus monkeys. Kociba and Schwetz (1982), citing Schnantz et al. (1979), report that rhesus monkeys given 1.7 ng/kg body weight TCDD in the diet had four of seven pregnancies terminate in abortion. This value is used in the current analysis for comparisons with doses received in larger wild mammals. In both of these laboratory studies, doses were administered in the diet. It is assumed that absorption from a laboratory diet is similar to the absorption from a wild diet; the analysis compares these doses directly to the daily dose to wild species from the ingestion of prey items. The toxic equivalency factor for TCDF is 1/10 of TCDF (U.S. EPA, 1989a). Therefore, the LOAEL values used for comparison to doses of TCDF ingested by large and small mammals are 10 times the LOAEL values for TCDD.

3.2 Methods for Estimating Exposures to Wildlife

To assess the potential for wildlife exposure to TCDD- and TCDF-contaminated sludge, this analysis adopts elements of models used by Sullivan et al. (1987) to estimate the potential TCDD and TCDF exposure to wild birds, and methods employed by Keenan et al. (1989) to estimate TCDD uptake by wild turkeys and deer. In addition, this analysis also incorporates work by Thiel et al. (1988) and the OME (1985) concerning the estimation of the steady state and nonsteady-state body burden of TCDD and TCDF.

Description of Calculations for Estimating Daily Dose

The calculations for estimating wildlife exposures proceed as follows. First, the dose to an individual animal is calculated based on the contaminant concentrations in soil, the TCDD and TCDF uptake rates by prey items, and the amount of each prey item ingested daily. The estimated dose is then compared to the LOAEL or NOAEL. Next, the steady state body burden for the animal is calculated. For migratory species, a body burden is calculated based on the length of time spent in the treated area. For birds, egg concentrations are then estimated based on the body burden of the female bird.

The dose of TCDD or TCDF to an animal_j may be calculated as follows:

$$\text{DOSE} = P_a \, TC \, [\sum_{i=1}^{n} (C_s \, BCF_i \, FC_{ij}) + C_s \, FS_j] \, AB_g/BW_j$$

where:

AB_g = gastrointestinal absorption rate of TCDD or TCDF, percent
BW_j = body weight of animal j, kilograms
C_s = concentration of TCDD or TCDF in soil, ng/kg

BCF_i = bioconcentration factor of food source i
FC_{ij} = fraction of animal j's diet that consists of food source i
FS_j = fraction of animal j's diet that consists of soil
P_a = percent of food originating from the land treated area
TC = total daily quantity of food consumed by the animal, kg

In this calculation, the soil concentration of TCDD or TCDF (C_s) is combined with bioconcentration factors (BCFs) of food items to yield the concentration of TCDD or TCDF in these organisms. Birds and small mammals ingest TCDD or TCDF when they prey on these items. Animals may also directly ingest some sludge if they dig for prey or burrow directly on the application site. To derive the total amount of TCDD or TCDF ingested daily by an individual of the species, the percent of the diet represented by each contaminated food source is multiplied by the concentration of TCDD or TCDF in that food source and by the total daily quantity of food consumed from the contaminated site. If necessary for consistency in comparison with LOAEL and NOAEL values derived in the literature, this estimated daily intake is adjusted by the bioavailability of TCDD and TCDF from food items (see section 3.1 for discussion of when such adjustments are necessary).

The estimated daily dose is then compared to the selected benchmark LOAEL or NOAEL, using the following equation:

$$DOSE_{\%LOAEL} = (DOSE/LOAEL) \times 100$$

or

$$DOSE_{\%NOAEL} = (DOSE/NOAEL) \times 100$$

where:

$DOSE_{\%LOAEL}$ = dose to wild animal expressed as a percent of the LOAEL
$DOSE_{\%NOAEL}$ = dose to wild animal expressed as a percent of the NOAEL
$DOSE$ = dose to the animal, ng/kg/day
$NOAEL$ = dose at which no adverse effects were observed in laboratory species, ng/kg/day
$LOAEL$ = lowest dose at which adverse effects were observed in laboratory species, ng/kg/day

The daily dose of TCDD or TCDF is compared to literature values for doses that cause reproductive effects, as discussed in section 3.1. The dose predicted for wild species is expressed as a fraction of the lowest dose observed to cause adverse effects (LOAEL), or as a fraction of the dose observed to cause no adverse effects (NOAEL).

Description of Calculations for Estimating Egg Concentrations

In order to determine the concentration of TCDD or TCDF in eggs laid by birds exposed to these contaminants, the body burden resulting from the ingestion of the daily dose must be calculated. If the bird ingests TCDD- and TCDF-contaminated food for a sufficient length of time to achieve steady-state, then the body burden is estimated as follows (OME, 1985):

$$B_{ss} = 1.443\ (DOSE)\ (T_{1/2})\ /\ t$$

where:

B_{ss} = steady-state body burden, ng
DOSE = dose to animal, ng/day
$T_{1/2}$ = half-life of TCDD or TCDF, days
t = time between doses, days (in this case, 1 day)

The steady state body burden is calculated as the dose multiplied by the half-life (in days), divided by the length of time between doses (in days). In this analysis, the dose is ingested daily, so t is equal to one day.

The body burden of migratory birds, who arrive at the land application site only a few weeks before egg-laying, may not reach steady-state. For these birds, the body burden can be calculated using an equation found in Thiel et al. (1988):

$$B_{ns} = [DOSE\ /(0.693/T_{1/2})]\ [1-(1/2)^{n}]$$

where:

B_{ns} = nonsteady state body burden, ng
DOSE = dose to animal, ng/day
$T_{1/2}$ = half-life of TCDD or TCDF
n = (time spent on treated site)/$T_{1/2}$

In this equation, the dose is first divided by (ln(2)/half-life); the result is then multiplied by a function of ratio of the time spent on the site to the half-life (denoted as n). The larger the ratio n, the closer the body burden is to the steady state body burden.

Finally, the concentration of TCDD or TCDF in bird eggs is derived using the following equation:

$$C_{egg} = B_{ns}\ TC / W_{egg}$$

or, $$C_{egg} = B_{ss}\ TC / W_{egg}$$

where:

B_{ss} = steady state body burden, ng
B_{ns} = nonsteady state body burden, ng
C_{egg} = concentration in egg, ng/kg (ppt)
TC = transfer coefficient from mother to egg, expressed as a fraction of body burden
W_{egg} = weight of the egg, kilograms

To predict the concentration of TCDD or TCDF in bird eggs, a transfer rate from the female to eggs is used to estimate the total quantity of TCDD or TCDF in the egg, in ng. The total quantity in the egg is then divided by the weight of the egg to obtain a egg TCDD or TCDF concentration in ng/kg.

The estimated egg concentrations can then be compared to lowest concentrations observed to cause adverse effects in laboratory studies:

$$C_{egg\%LOAEL} = (C_{egg}/LOAEL_{egg}) \times 100$$

where:

$C_{egg\%LOAEL}$ = concentration in egg expressed as a percent of the $LOAEL_{egg}$
C_{egg} = concentration in egg, ng/kg (ppt)
$LOAEL_{egg}$ = lowest concentration at which adverse effects were observed in eggs in laboratory, ng/kg (ppt)

The TCDD or TCDF concentration in the egg is compared to a selected literature value for the lowest concentration observed to produce adverse effects in embryos in laboratory studies, discussed in section 3.1. The concentration predicted for wild bird species is expressed as a percent of the LOAEL for eggs.

Data Sources Used To Estimate Exposures to Wildlife

The data sources and model inputs for estimating wildlife exposures are summarized in Table 3.2.A. The following sections describe each input parameter and document the data sources used to obtain values for these input parameters.

Data Sources and Model Inputs Used in the Selection of Species Examined

To select the species of interest, this analysis relied on the expertise of biologists with the Natural Heritage Programs in the seven states of interest (Georgia, Maine, Maryland, Mississippi, Ohio, Pennsylvania, and Wisconsin). In each state, the Natural Heritage experts provided information on common avian and mammalian species as well as endangered species believed to inhabit regions of the state where land application is practiced. Data on the occurrence of mammals in each state were also obtained from Caras (1967). From the species identified in the seven states, nine avian species and seven mammalian species were initially selected for study. They are the following: loggerhead shrike (Lanius ludovicianus), American woodcock (Scoplax rusticola), pine warbler (Dendroica pinus), eastern meadowlark (Sturnella magna), great crested flycatcher (Myiarchus crinitus), tree swallow (Iridoprocne bicolor), American robin (Turdus migratorius), wood thrush (Hylocichla mustelina), and eastern bluebird (Siala sialis sialis). The mammalian species chosen were: nine-banded armadillo (Dasypus novemcinctus), least shrew (Cryptotis parva), eastern mole (Scalopus aquaticus), striped skunk (Mephitis mephitis), virginia opossum (Didelphis virginiana), river otter (Lutra canadensis), and the little brown bat (Myotis lucifugus). The possum, river otter, little brown bat and striped skunk occur in all of the seven states, and the least shrew and eastern mole occur in six of the seven states (Caras, 1967)[2]. Only species judged to be at risk for exposure to TCDD and TCDF were selected. In general, species were selected based on their dietary habits. Those species that ingest significant quantities of prey items that bioconcentrate TCDD and TCDF, such as soil invertebrates, earthworms, insects and small mammals, were considered to be at greatest risk. Other considerations were also incorporated into the selection of species. For example, the gray bat (Myotis grisescens) was selected for study in place of the little brown bat because the gray bat is considered

---

[2] The armadillo occurs only in Mississippi, but was included in the analysis because its dietary habits (ingestion of soil and soil-dwelling organisms) may put it at risk from exposure to TCDD and TCDF.

Table 3.2.A. Assumptions and Parameter Values - Land Application: Wildlife Exposures

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Uptake rates for vegetation eaten by wildlife	0.01%	2%	15%	Assumes wildlife eat above-ground plants only.	High: Young et al 1983 Low: Wipf et al 1982 Best: subgroup on Dioxin uptake in Terrestrial Plants (6/23/89 memo)
BCF for earthworms	0.2	3.5	10	The best estimate was reported at a site where paper mill sludges were applied. High and low values are range reported by Martin et al citing Reinecke and Nash (1984). Higher values have been reported for Seveso, but soil concentrations there were at much higher levels than would be expected at sludge-applied sites (Martinucci et al 1983, as cited in Sullivan et al 1987).	Martin et al 1987
BCF for insects	0.4	1	1.5	This is the approximate range of BCFs for insects at Elgin AFB, FL. Low is for composite of soil and plant-borne insects, best estimate is for burrow spiders, high is for insect grubs.	Young and Cockerham 1985
BCF for small mammals	1.3	1.4	1.4	These values are for whole body rather than just the liver.	Martin et al., 1987
BCF for fish from sediment (food source for river otter)	0.0967	0.0967	5		Low and best: Memo from R. Morcock "Bioconcentration Factors for 2,3,7,8 - TCDD and 2,3,7,8 - TCDF" August 8, 1989 High: EPA, 1988

Table 3.2.A. (cont.) Assumptions and Parameter Values - Land Application: Wildlife Exposures

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Large mammals River other	0.5 0.06	1.0 1.0	1.0 1.0	Large mammals feed from treated area exclusively in best and high. Low same as birds. Low river otter % calculated as size of one side of 50 acre treatment site/size of otter's home range.	Home ranges from Wild Mammals of North America; Otter: Toweill and Tabor, "River Otter" In: Wild Mammals of North America
Whole-body elimination rate, TCDD: birds	15 days	21 days	31 days	Best estimate: calculated based on information provided on blue birds provided in Thiel et al 1988. Low and high from OME, 1985 for small vertebrates.	Thiel et al 1988 Ontario Ministry of the Environment Scientific Criteria Document for Standard Development No. 4-84. September 1985.
Small mammals	15 days	31 days	37	Best: data from rat oral; low from hamster oral; high from mouse, i.p.	Ontario Ministry of the Environment Scientific Criteria Document for Standard Development No. 4-84. September 1985.
Large mammals	30 days	60 days	365	Best: 2 x data for rat oral; low 2x hamster oral; high, monkey.	OME, 1985
Transfer of dioxin from hen to eggs: (% of body burden)	3.3%	4.8%	6.2%		Thiel et al. 1988
Time spent on-site before egg-laying weeks	4	6-8	10	Best: 6-8 weeks depending on species, except loggerheadshrike, which is not migratory in its range. Low and high are arbitrary.	From A.C. Bent Series on Life Histories Of Birds.
Egg mass		species-specific			From: Schonwetter (1960-1983) Thiel et al. (1987) Bent (1964)

Table 3.2.A. (cont.) Assumptions and Parameter Values - Land Application: Wildlife Exposures

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of dioxin absorbed from food	0.60	0.70	.95	Low: low end of range for food given by workgroup for non-oily foods Best: high end of range for non-oily foods High: high end of range for absorption of oily foods.	"Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances." memo from Ivan Boyer, FDA, 6/22/89
Total food consumption for birds	Data from Nice 1939 as cited in Kenaga 1973	Data from Nice 1939 as cited in Kenaga 1973	Data from Kendeigh, 1969, as cited by Kenaga 1973		Kenaga, E.G. "Factors to be Considered in the Evaluation of the Toxicity of Pesticides to Birds in Their Environment." In Coulston, F. and F. Korte, ed. Environmental Quality and Safety: Global Aspects of Chemistry, Toxicology and Technology as Applied to the Environment; Academic Press 1973
Total food consumption for mammals		Used data from Davis & Golly (1963) and from Wild Mammals of North America		Where specific species were not included on Davis and Golly table, we used the ratio of consumption to body weight for a similar animal, and then multiplied by the weight of the animal of interest.	Davis and Golly, 1963 Some data from Wild Mammals of North America
Mix of food sources		Species specific data			Bird data A.C. Bent Series on Life Histories of Birds; mammal data from Wild Mammals of North America; and from Mammals of Eastern United States

Table 3.2.A. (cont.) Assumptions and Parameter Values - Land Application: Wildlife Exposures (cont.)

Input parameter	Low	Best estimate	High	Notes/explanation	Reference
Percent of diet that is soil:					
Eastern meadowlark	0.1%	1%	10%	Southern meadowlark described in Cockerham and Young as "fastidious preeners" that ingest soil during preening. No range for soil ingestion given, so range here is arbitrary.	Young and Cockerham, 1985
Nine-banded armadillo	1%	10%	20%	Described as often ingesting "large amounts of soil" No range of percentages were given, so range here is arbitary.	Galbreath, G.J. "Armadillo." In Chapman J.A. and G.A. Feldhamer, ed. Wild Mammals of North America. John's Hopkins University Press, 1982.
Eastern mole	0.1%	1%	10%	Beachmouse exposed to soil through burrowing, preening. Mole may have similar exposure. Range given here is arbitrary.	Young and Cockerham, 1985
Virginia opossum	1%	7%	10%	Best guess: analysis of stomach contents for opossum in Pennsylvania revealed 7% sand and stones. Low and high arbitrary.	Gardener, A.L. "Virginia Opposum." In: Chapman, J.A. and G.A. Feldhamer, ed. Wild Mammals of North America. Johns Hopkins University Press, 1982.
Fraction of food sources from sludge applied land:					
Birds	0.50	1.0	1.0	Best and high assume birds feed from treated area only. Low estimate from Sullivan.	Sullivan et al., 1987
Small mammals	0.5	1.0	1.0	Small mammals assumed to feed completely from treated area. Low estimate same as birds.	

endangered in Georgia, a state where land application of sludge is practiced (personal written communication, Carol Corbat, Georgia Department of Natural Resources, Natural Heritage Inventory). However, since the food mix and the daily consumption of food per kilogram body weight are similar for the gray bat and the little brown bat, exposure estimates for the little brown bat (per kilogram body weight) should be approximately the same as those estimated for the gray bat.

For avian species, the analysis focussed on female birds because they have the potential to transfer a portion of their body burden to eggs during the breeding season. To the extent that other members of the species (such as males or rapidly-growing nestlings) are more sensitive than females to the adverse effects of TCDD or TCDF, this analysis may underestimate risk to these species.

Soil-dwelling organisms such as earthworms are directly exposed to contaminated soil; estimates of TCDD and TCDF exposure to these organisms could have been included in this analysis. However, Eisler (1986), citing Reinecke and Nash (1984), reported that two species of earthworms held in soils containing 5 parts per million (ppm) of 2,3,7,8-TCDD showed no adverse effects. Since a concentration of 5 ppm is 7300 times higher than the highest sludge concentration reported for any mill that currently land-applies sludge, it is assumed that current land application practices will have no adverse effects on the earthworms themselves.

Predatory/scavenger avian or mammalian species could also be exposed to TCDD or TCDF through the food chain. Because the land application of sludge is a localized practice, typically covering fewer than a few hundred acres, species with large hunting territories, such as osprey, bald eagles, and herons, are unlikely to obtain a large fraction of their diets from a single sludge land application site; therefore, these organisms are not quantitatively evaluated here. However, it is possible that these species may accumulate significant levels of TCDD or TCDF because of their position at the top of the food web; for this reason, these species may warrant further analysis, especially if the land application of sludge is practiced on larger or many contiguous tracts of land in the future. The analysis does estimate exposure to one mammal species with a territory relatively large compared to the land application site: the river otter. This species, which ingests fish that bioconcentrate TCDD and TCDF from river sediments, is considered in this analysis because it is a threatened species in an area of one state where land application is practiced.

Data Sources for Estimating Soil Concentrations

Methods for estimating soil concentrations at the seven land application sites considered in this analysis are described in Appendix A. For human risk estimates, the average soil concentration over the lifetime of human being, assumed to be 70 years, is used. For wildlife species, this concentration is inappropriate for two reasons: the lifespans of the wildlife species examined are shorter than 70 years, and the benchmark effects levels to which estimated doses are compared were not based on lifetime exposures. Therefore, this analysis uses the soil concentrations at the land application sites during a single year as the basis for the wildlife assessment. The average TCDD and TCDF concentrations over one year for each land application site are summarized in Table 3.2.B.

Data Sources and Model Inputs for Body Weights of Animals

In order to compare a dose ingested by a wild animal to the doses which induce effects in laboratory animals, dose must be expressed in terms of milligrams per kilogram of body weight per day. The body weights of female birds were obtained from a monograph produced by the Western Bird Banding Association, which lists the average body weights of 686 species of North American birds (Dunning, 1984). The body weights of all mammals except shrews and bats were obtained from Chapman and Feldhamer (1982). Body weights for bats and shrews were obtained from Hamilton (1979). The body weights are summarized in Table 3.2.C.

Data Sources and Model Inputs for Estimating the Fraction of Food from Treated Areas

In this analysis, the "high risk" and "best estimate" scenarios assume that the species considered obtain all of their food from the treated area. This assumption is derived from the fact that home ranges of most of these species could be encompassed by the sludge treated area. Even those animals with home ranges larger than the treated area are likely to be attracted to the treated area for foraging, since the presence of sludge nutrients may increase the availability of food in the treated area compared to surrounding areas. For the "low risk" estimate, it is assumed for all species except otters that 50 percent of an animal's diet originates in the treated area. This assumption is consistent with that used in Sullivan et al. (1987). River otters have a much larger home range than any other of the species considered in this analysis. Toweill and Tabor (in Chapman and Feldhamer, 1982) state that the home range of otters varies 7 to 15 kilometers. Assuming an average site of 20.2 acres affects a 450 meter tract of an adjacent river, the percent of an otter's range that would be affected would vary from 3% to 6.4%. Therefore, for the "low risk" estimate, it is assumed that 6 percent of an otter's diet is affected by the treated area.

Data Sources and Model Inputs for Estimating Mixes of Food Sources

The food mixes for each species are summarized in Table 3.2.D. Food sources are assigned to the following categories: earthworms, insects, plant matter, soil, small mammals and fish (river otters only). Data on the percent of each type of food consumed by birds was obtained from the

Table 3.2.B. Characteristics of Land Application Sites and Soil Concentrations Used in Wildlife Analysis

State	Type of application	Application rate (DMT/Ha)	Years land receives sludge	Incorporation Depth (cm)	Area receiving sludge (Ha/Year)	Sludge concentration TCDD	Sludge concentration TCDF	Soil TCDD conc (ppt) 1 yr.	Soil TCDF conc (ppt) 1 yr.
Georgia	forest	2,065	1	2.5	81	220	610	181	501
Maine	forest	40	1	2.5	607	13	55	1	5
Maryland	mine	224	1	0	27	80	471	80	471
Mississippi	agriculture	58	70	15	405	681	0	14	0
Ohio	mine	224	1	0	81	145	795	145	795
Pennsylvania	agriculture	18	20	15	30	34	10	.2	.07
Wisconsin	forest	40	1	2.5	1,012	109	1300	9	106

Table 3.2.C. Body Weights and Daily Food Consumption of Animals Affected by Land Application of Sludge

Birds	Body weight, grams	Daily food consumption grams, dry weight from Nice, 1939	Daily food consumption grams, dry weight from Kendeigh, 1969
Bluebird	31.6	4.522	8.915
American Robin	77.3	8.84	14.73
Great Crested Flycatcher	33.5	5.09	9.21
Loogerhead Shrike	47.4	6.4	11.19
Eastern Meadowlark	76.0	8.74	14.59
Tree Swallow	20.1	3.63	6.92
Pine Warbler	11.9	2.58	5.18
Woodcock	219.0	*	*
Woodthrush	47.4	6.4	11.19

Mammals	Body weight, grams	Daily food consumption grams, wet weight	Source
Nine-Banded Armadillo	4000	120	Davis and Golly, 1963
Grey Bat	8	8	Hamilton, 1979
Eastern Mole	50	25	Chapman and Feldhamer, 1982
River Otter	9,000	1,000	Chapman and Feldhamer, 1982
Virginia Opossum	3,500	105	Davis and Golly, 1963
Least Shrew	5	5.5	Davis and Golly, 1963
Striped Skunk	2,300	46	Davis and Golly, 1963

Table 3.2.D. Mix of Food Sources for Birds and Mammals

	Food Type, Percent					
	Earthworms	Insects	Plants	Small Mammals	Soil	Fish
Birds:						
Bluebird	0	68	32	0	0	0
American Robin	2	98	0	0	0	0
Great Crested Flycatcher	0	93.7	6.3	0	0	0
Loggerhead Shrike	0	72	0	28	0	0
Eastern Meadowlark	0	74	25	0	1	0
Tree Swallow	0	80	20	0	0	0
Pine Warbler	0	95	5	0	0	0
American Woodcock*	100	0	0	0	0	0
Woodthrush	0	62	38	0	0	0
Mammals:						
Nine-Banded Armadillo	0	45	0	45	10	0
Grey Bat	0	100	0	0	0	0
Eastern Mole	34	50	15	0	1	0
Virginia Opossum	8	9	22	30	7	0
Least Shrew	50	50	0	0	0	0
Striped Skunk	0	90	10	0	0	0
River Otter	0	0	0	0	0	100

---

*Looked only at consumption of earthworms; ignored other food sources.

series of books on the life histories of birds by A.C. Bent, published by Dover Press (Bent, 1955, 1962, 1963, 1963a, 1965). The one exception was the food consumption data for woodcocks. Woodcocks are avid consumers of earthworms. Since the bioconcentration of TCDD and TCDF in earthworms is higher than other food sources, this analysis estimates woodcock TCDD and TCDF exposure from its consumption of earthworms alone, and assumes other food sources contribute relatively little to total woodcock TCDD and TCDF exposure. Sheldon (1967) reported that the total daily consumption of earthworms by woodcock is 150 grams.

Data on the mix of food sources for all mammals except shrews were obtained from Chapman and Feldhamer (1982). The data on mix of food sources for shrews were obtained from Hamilton (1979). When data on mix of food sources were reported for more than one area of the country, the data from a state where land application is practiced, or a nearby state, were used.

Data Sources and Model Inputs for Estimating the Fraction of the Diet Consisting of Soil

Some mammals and birds will ingest soil inadvertently, while consuming ground-dwelling prey or while preening or burrowing. Young and Cockerham (1985) reported relatively higher liver concentrations of TCDD for Southern meadowlarks residing around a TCDD-contaminated area at Elgin AFB in Florida. They hypothesize that the birds ingest some soil while preening. Based on the Young and Cockerham report, this analysis assumes that the eastern meadowlark ingests a small amount of soil during preening. It is arbitrarily assumed that between 0.1 and 10% of the diet consists of soil, with a best estimate of 1%. Young and Cockerham (1985) also postulated that beachmice living in the same area may have elevated liver concentrations of TCDD due to their burrowing and preening behavior. Eastern moles, who are also burrowers, may have similar opportunities for inadvertent soil ingestion. For this analysis, it is arbitrarily assumed that from 0.1 to 10% of a mole's diet consists of soil ingested while foraging or burrowing, with a best estimate of 1%.

Galbreath (in Chapman and Feldhamer, 1982) reported that armadillos often ingest "large amounts of soil," although the author did not report what percent of the diet consists of soil. This analysis assumes that an armadillo's diet could consist of 1 to 20% percent soil, with a best estimate of 10%.

Gardener (in Chapman and Feldhamer, 1982) reported that analysis of stomach contents of virginia opossums found in Pennsylvania contained approximately 7% sand and stones. This value is used as an estimate of the percent of the opossum's diet consisting of soil; a range from 1 to 10% is used for low and high estimates.

Data Sources and Model Inputs for Bioconcentration Factors for Earthworms

The tendency of earthworms to bioconcentrate TCDD has been shown in several studies. Many of the studies that yielded high bioconcentration factors were conducted at sites (e.g., Seveso) where soil TCDD concentrations were quite high; these values were considered inappropriate for use in this analysis, where much lower soil concentrations of TCDD are expected. Reinecke and Nash (1984), as cited in Martin et al. (1987) reported earthworm TCDD concentrations 0.2 to 10 times higher than soil concentrations. As a best estimate of the bioconcentration of TCDD and TCDF in earthworms, this analysis uses the earthworm bioconcentration value reported at an actual site where paper mill sludges containing TCDD and TCDF had been applied (Martin et al., 1987), 3.5, while using the range cited by Martin et al. (1987) for the low and high estimates.

Data Sources and Model Inputs for Bioconcentration Factors for Insects

Young and Cockerham (1985) reported the average concentrations of TCDD in a number of insect species and families at a TCDD-contaminated site at Elgin AFB in Florida. Comparing insect concentrations to the average soil concentrations reported for the same area, the bioconcentration factor for insects varied from zero for grasshoppers, to 0.4 for a composite of soil and plant-borne insects, to a high of 1.5 for insect grubs. For insects, a value of 1 is used as the best estimate for the bioconcentration factor; the values 0.4 and 1.5 are used for the low and high estimates, respectively.

Data Sources and Model Inputs for Plant Uptake Rates

The low estimate for the uptake of TCDD or TCDF from soil into plant tissues (0.01%) is derived from Wipf (1982). The high estimate of the plant uptake rate is taken from a study by Young (1983). For the best estimate of plant uptake, this analysis uses the value suggested by EPA (1989b) for above-ground plants. Since all of these values were derived from studies on cultivated plants, the use of these values in this analysis is based on the assumption that wild plants take up TCDD and TCDF at the same rate as cultivated crops. Furthermore, the use of this range assumes that wild animals consume only above-ground crops. If animals consume roots, which have higher uptake rates than above-ground portions of plants, animals may have higher exposures than those estimated in this analysis.

Data Sources and Model Inputs for Bioconcentration/Bioaccumulation Factors for Small Mammals

Martin et al. (1987) reported that the whole body bioconcentration factor for deer mice was about 1.4. The authors compared this value to whole body bioconcentration factor of 1.3 reported for field mice taken from the Seveso area. In contrast, Thalken and Young (1983) reported values for beachmice liver tissue that ranged from 6.7 for females to 18 for males. For this analysis, the whole body bioconcentration factors were judged to be more appropriate than liver-only values. It is important to note that these bioconcentration factors were derived from small mammal species that may get little TCDD or TCDF exposure from their diet (i.e., mice eat large quantities of seeds which would not be expected to contain significant amounts of TCDD or TCDF). Small mammals that consume prey items that bioconcentrate TCDD and TCDF may have higher levels of TCDD and TCDF in their bodies.

Data Sources and Model Inputs for Bioconcentration Factors for Fish

The fish to sediment ratio used in the "low risk" and "best estimate" scenarios to estimate the concentration of TCDD in fish consumed by river otters is derived from a recent EPA review of the literature (EPA, 1989c). This value is assumed to be 0.0967 (whole body, wet weight). In the "high risk" scenario, the fish-to-sediment ratio is obtained from a review of literature discussed in EPA (1988). Otters are assumed to eat the entire body of the fish. For simplicity, it is assumed that the sediment TCDD and TCDF concentrations near all land application sites are, on average, 1/1000 the TCDD and TCDF concentrations in the soil at the land application site. This value is based on the average sediment-to-soil ratios calculated in this report for the seven land application sites.

Data Sources and Model Inputs for Total Food Consumption Per Day

A summary of the data used for total daily food consumption estimates is presented in Table 3.2.C. Total food consumption data for otters and moles were obtained from Chapman and Feldhamer (1982). Data on bats were found in Hamilton (1979). For the least shrew, data were found on a table of food consumption from Davis and Golly (1963). From this table, the total consumption values for the armadillo, opossum and striped skunk were estimated by applying the food intake/body weight ratio for raccoons to the body weights of these animals.

Kenaga (1973) presented data from two studies (Nice, 1939 and Kendeigh, 1969) relating total daily food consumption for birds (in dry weight) to their body weights. The data from these two studies was used to predict a regression equation relating the log of body weight to the log of the ratio of food consumption to body weight. For this analysis, the body weights for birds from Dunning (1984) were used in these equations to predict the total daily food consumption, in dry weight. The equation based on Nice (1939) data is used for the best estimate, and the equation based on Kendeigh (1969) data is used as the high estimate. To use the values derived, dry weight values must be converted to wet weight. To convert the dry weight values to wet weight, earthworms are assumed to be 83% water by weight (French et al. 1957, cited by Kenaga, 1973). No data on the wet weight of other food sources were found; therefore, the percent water of other food sources is arbitrarily assumed to be 50%.

Sheldon (1967) reported that the American woodcock consumes 150 grams per day of earthworms. Since earthworms bioconcentrate TCDD and TCDF at a higher rate than any other food source, the TCDD and TCDF exposure estimate for woodcocks is based on its consumption of earthworms alone; other food sources are assumed to contribute relatively little to the total dose.

Data Sources and Model Inputs for Absorption of TCDD or TCDF from GI Tract

The absorption of TCDD and TCDF from food sources is needed in order to compare the dose ingested by wild birds to results from laboratory studies where TCDD was delivered to chickens in a corn oil matrix. FDA (1989) recently reviewed studies on the bioavailability of TCDD ingested in a variety of matrices, and concluded that 60-70 of TCDD is ingested from non-oily foods, while 85-95% is ingested from oily foods. For the best estimate, it is assumed that absorption of TCDD and TCDF from all food sources in a wild animal's diet is 70%, while values of 60% and 95% are used to represent the low and high estimates, respectively.

For mammals, no adjustment is necessary, because in the laboratory studies to which wildlife exposure estimates are compared, researchers administered TCDD to the animals through the diet. This analysis assumes that the TCDD and TCDF absorption rate from a laboratory diet is the same as the TCDD and TCDF absorption rate from wild diets.

Data Sources and Model Inputs for Estimating Body Burdens of TCDD and TCDF

Egg concentrations of TCDD and TCDF are a function of the body burden of TCDD and TCDF in the female laying the eggs. In order to calculate the transfer of TCDD and TCDF from the female bird to her offspring, the body burden of the female bird must be calculated. The equation for calculating the steady-state body burden is derived in OME (1985). However, not all organisms will be exposed to the contaminated area long enough to reach steady state. In fact, of all bird species analyzed here, only the loggerhead shrike is considered nonmigratory. For migratory organisms, a pharmacokinetic model described in Thiel et al. (1988) is used to predict the body burden at the time of reproduction. One input to this model is the length of time exposed to TCDD and TCDF before reproduction. For a migratory bird, it is assumed that the exposure begins upon arrival in the northern portion of the range and continues until the time when the eggs are laid. For the bird species analyzed, this is approximately 6-8 weeks, depending on the species. The value for each species was obtained by calculating the number of weeks between the first spring sightings of the birds in the states where land application is practiced and reported egg-laying dates in these states (Bent 1955, 1962, 1963, 1963a, 1964).

Another input required for the pharmacokinetic model is the half-life of TCDD and TCDF in wild birds. OME (1985) reports the half-life for whole body elimination of TCDD and TCDF in several species, including rats, mice, hamsters, and monkeys. No data were found for wild birds. However, from field data presented for bluebirds by Thiel et al. (1988), an estimate of the half-life of TCDD in birds was indirectly estimated. Because the TCDD soil concentrations were not reported in the study, the average soil concentrations over one year were derived using the sludge concentrations of TCDD applied to the treated area, assuming a TCDD half-life in soil of 10 years, and assuming that the sludge was combined with 1 inch of forest floor litter. Information on the dietary habits of bluebirds from Bent (1964) and an estimate of the bluebird's total consumption of food per day from Kenaga (1973) were used to estimate the daily dose of TCDD to the bluebird at the site. In addition, information found in Bent (1964) on the time of arrival and egg dates in Wisconsin (the state where the Thiel et al. (1988) study was conducted) was used to estimate the length of time bluebirds were residing in the treated area before reproducing. Finally, the average weights of bluebird eggs and the percent of TCDD transferred from the bluebird hen to her eggs was obtained from the Thiel et al. (1988) study. All of information was entered into the pharmacokinetic model, and the value for the half-life of TCDD was adjusted until the model yielded values that corresponded to the actual TCDD concentration in bluebird eggs reported in Thiel et al. (1988). The value estimated for half-life is 21 days. This value is in good agreement with values reported in OME (1985) for other small vertebrates, such as rats and mice, which range from 17 to 31 days, and is used as the best estimate. For a low and high estimate of the half-life of TCDD in wild birds, a range of TCDD half-lives for small vertebrates from 17 to 31 days is used (OME, 1985). Martin et al. (1987) states that the half-life for the whole body elimination of TCDF is one-eighth the half-life of TCDD. Under this assumption, the estimated half-life for TCDF in wild birds is 2.6 days, and ranges from 2.1 to 3.9 days.

For the estimate of half-life of TCDD in mammals, data reported in OME (1985) is used. For small mammals, a value of 31 days represents the best estimate. This value was observed in rats administered TCDD orally. The low estimate is 15 days, the value observed for hamsters administered TCDD orally, while the high estimate 37 days, the value observed in mice administered TCDD i.p. For larger mammals (i.e., over 1 kg), the best estimate for half-life of TCDD is 60 days. This value is twice the half-life observed in rats given TCDD orally. The low estimate is 30 days, twice the hamster value, while the high estimate of 365 days is the half-life of TCDD observed in monkeys. Again, it is assumed that the half-life for the whole body elimination of TCDF is one-eighth the half-life of TCDD (Martin et al., 1987). Under this assumption, the half-life of TCDF in small mammals is 3.9 days (with low and high estimates of 1.9 days and 4.6 days). The half-life for TCDF in large mammals is 7.5 days (ranging from 3.8 days to 45.6 days).

Data Sources for the Transfer Coefficient from the Hen to Eggs

Thiel et al. (1988) estimated the transfer of TCDD from female bluebirds to eggs by measuring the concentration in the body of the female bluebird and the concentration in the eggs. These researchers reported that a mean of 4.8% of the female's body burden of TCDD was transferred to each egg, with a range from 3.3% to 6.2%. A value 4.8% represents the best estimate of transfer rate for TCDD and TCDF, while values of 3.3% and 6.2% are used for the low and high estimates, respectively.

Data Sources for the Egg Weights of Birds

The quantity of TCDD and TCDF transferred from the female bird to the eggs must be divided by the weight of the egg to obtain an estimated egg concentration. Egg weights were reported for bluebirds and tree swallows in Thiel et al. (1988) and for eastern meadowlarks in Bent (1964). All other egg weights were obtained from Schonwetter (1960-1984).

3.3 Summary of Results

Table 3.3.A. presents a summary of the results of the "best estimate" analysis of risks to birds foraging from land application sites. This table shows the lowest and highest estimates of the daily dose (expressed as a percent of the NOAEL) among the seven land application sites assessed in this analysis. The table also indicates the states where the lowest and highest values occur. Similarly, Table 3.3.B. summarizes the risks to bird eggs, while Table 3.3.C. presents the risks to mammalian species. Appendix D.2. contains the detailed risk results for the "best estimate" analysis of risks to wildlife. In this Appendix, a series of tables is presented for the best estimate of risks to wildlife. There are two tables for each state where land application is practiced, one for birds and one for mammals. The table for birds presents the estimated dose of TCDD and TCDF in ng/kg/day, the estimated egg concentration in ppt, and the comparison of dose of TCDD and TCDF to the NOAEL

Table 3.3.A. Summary of Risks to Birds ("Best Estimate")

Species	Lowest Value for Dose as a Percent of NOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of NOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	0	0	PA	309	169	OH
American Robin	1	0	PA, MS (TCDF)	413	114	GA
Great Crested Flycatcher	0	0	PA, MS (TCDF)	328	91	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	520	285	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	160	88	OH
Tree Swallow	2	1	ME	334	92	GA
Pine Warbler	3	1	ME	476	132	GA
Woodcock	15	8	ME	2761	764	GA
Woodthrush	1	1	ME	194	54	GA

Table 3.3.B. Summary of Risks to Bird Eggs ("Best Estimate")

Species	Lowest Value for Concentration as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Concentration as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	1	0	PA	675	55	OH
American Robin	1	0	PA, MS (TCDF)	1059	44	GA
Great Crested Flycatcher	1	0	PA, MS (TCDF)	624	26	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	720	49	OH
Eastern Meadowlark	1	0	PA, MS (TCDF)	382	31	OH
Tree Swallow	5	0	ME	818	34	GA
Pine Warbler	4	0	ME	679	28	GA
Woodcock	34	3	ME	6237	288	GA
Woodthrush	2	0	ME	405	17	GA

Table 3.3.C. Summary of Risks to Mammals ("Best Estimate")

Species	Lowest Value for Dose as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Nine-banded Armadillo (1)	31	0	MS	31	0	MS
Grey Bat	2	0	PA, MS (TCDF)	1810	501	GA
Eastern Mole	2	0	PA, MS (TCDF)	1540	426	GA
River Otter	0	0	(2)	0	0	(2)
Virginia Opossum	0	0	PA, MS (TCDF)	288	80	GA
Least Shrew	6	0	PA, MS (TCDF)	4480	1240	GA
Striped Skunk	0	0	PA, MS (TCDF)	192	53	GA

(1) Armadillo only occurs in Mississippi

(2) River otter dose less than 0.5% in all states

for adult birds derived in section 3.1. The estimated dose is expressed as a percent of the NOAEL. Similarly, the egg concentrations are expressed as a percent of the LOAEL for eggs derived in section 3.1. For mammals, the tables present the estimated dose and the estimated steady state body burden of TCDD and TCDF. The dose is expressed as a percent of the appropriate LOAEL for that species. The sources used to derive the LOAELs are discussed in section 3.1.

The results confirm that those species whose diets consist largely of prey species that bioconcentrate TCDD and TCDF are at the greatest risk from the land application of sludges containing TCDD and TCDF. For example, at all seven sites assessed, the avian species at greatest risk is the American woodcock, a species that consumes relatively large quantities of earthworms. At the land application site with the highest estimated soil concentrations of TCDD, the best estimate of the daily dose of TCDD ingested by this species is about 28 times the estimated NOAEL; the daily dose of ingested TCDF is about 8 times the estimated NOAEL. The eggs of woodcocks residing on this site are estimated to have TCDD concentration about 62 times higher than the TCDD LOAEL of 65 ppt and a TCDF concentration that is about 3 times higher than the TCDF LOAEL of 650 ppt. Even at a land application site with a relatively low soil concentration of TCDD, the woodcock ingests a dose of TCDD that is about 15 percent of the TCDD NOAEL, while the eggs of woodcocks at this site are estimated to have a concentration of TCDD that is about 34 percent of the TCDD LOAEL for eggs.

Similarly, the mammalian species at greatest risk from land application of TCDD- and TCDF-contaminated sludge is the least shrew. Fifty percent of this species' diet consists of earthworms. This species also consumes large quantities of food relative to its body weight, leading to a greater dose per body weight than other species. At the site with the highest TCDD concentrations, the estimated daily dose of TCDD ingested by the shrew is about 45 times higher than the TCDD LOAEL for small mammals.

The wildlife risk assessment results also show that species whose diets contain only moderate percentages of prey species that bioconcentrate TCDD and TCDF may exceed toxicity thresholds if the concentrations of TCDD and TCDF are sufficiently high. For example, at the site with the highest TCDD and TCDF concentrations, adults of all avian species assumed to reside there exceed the TCDD NOAEL. The eggs of these species are estimated to have concentrations of TCDD that exceed the TCDD LOAEL for eggs. Furthermore, all of the mammals at this site except the otter also exceed the TCDD LOAEL.

The wildlife risk assessment results imply that individual members of certain wildlife species are at risk for reproductive and other effects from the land application of pulp and paper mill sludges containing TCDD and TCDF. This result assumes that wild species are at least as sensitive to the effects of TCDD and TCDF as laboratory species. Adverse effects on individuals may be important if the individuals affected are members of species that are endangered or threatened. In Maryland, for example, the loggerhead shrike, a threatened species, ingests a daily dose that is almost three times the TCDD NOAEL for nonmigratory birds. Furthermore, the eggs of this species have a TCDD concentration that is almost four times the TCDD LOAEL for eggs. The loggerhead shrike is considered a threatened species in that state.

This assessment does not attempt to quantify the effects of TCDD and TCDF on populations or ecosystems. However, the results of assessment show that at certain land application sites, the reproductive capability of individuals of certain species may be affected, assuming that wild species are at least as sensitive to the effects of TCDD and TCDF as laboratory species. Effects on the reproductive capability of a sufficient number of individual members of a species may lead to overall population effects for that species in that area.

Since this analysis was completed, the Environmental Effect Branch of the Office of Toxic Substances updated this assessment with the most recent information available on TCDD and TCDF toxicity and exposure to fish and wildlife. Based on the additional information, the update provides conclusions on the risks of TCDD- and TCDF-contaminated sludge to aquatic and terrestrial organisms. The EEB update is found in Appendix D of this report.

3.4 Comparison of Wildlife Risk Model to Results of Field Studies

Two field studies of the effects of the land application of pulp and paper sludge on wildlife have been conducted in Wisconsin: Thiel et al. (1988) and Martin et al. (1987). The general conclusions of the Thiel and Martin studies were that few or no effects were observed on the wildlife populations inhabiting the area of the sludge application when compared to control populations. These general conclusions are supported by the results of the present analysis of land application in Wisconsin. As can be seen from Appendix Tables D.1.F, D.2.F, and D.3.F, for almost all bird species, the highest estimates of adult daily doses are less than 40 percent of the TCDD NOAEL, indicating little potential risk to these species. The estimated egg concentrations for almost all bird species range from low estimates well below the LOAEL (7 percent or less of the TCDD LOAEL) to high estimates 1.5 times or less the TCDD LOAEL. Appendix Tables D.1.L, D.2.L, and D.3.L show relatively low risks to mammals at the Wisconsin site, although the highest estimate of dose slightly exceeds the LOAEL for bats and moles, and exceeds the LOAEL for shrews.

Species-specific data reported in the Thiel et al. (1988) study can be used to evaluate the predictive ability of the wildlife exposure model. Thiel et al. (1988) reported the egg concentrations of several species of birds, including bluebirds and robins. These values can be compared to values predicted by the model when the same TCDD and TCDF sludge concentrations are used.[3] Thiel et al. (1988) did not report soil TCDD and TCDF concentrations; only estimated sludge concentrations are given. However, the Martin et al. (1987) study, conducted earlier in the same general area as the Thiel study, reported both sludge and resulting soil concentrations for TCDD and TCDF. Applying the sludge:soil concentration ratios observed in the Martin study to the sludge concentrations reported in the Thiel study yields estimated soil concentrations of 16.1 ppt TCDD and 257 ppt TCDF.

Using these values for estimated soil concentrations, the "best estimate" wildlife exposure model predicts that bluebird TCDD egg concentrations are 49 ppt; the low estimate is 3.5 ppt, and the high estimate 130 ppt. Thiel et al. (1988) reported bluebird egg TCDD concentrations of 6-11 ppt. The Thiel et al. (1988) range is close to the low estimate calculated by the model. For the low estimate, the model uses a BCF value of 0.4 for the soil invertebrates/insects, the primary source of food for bluebirds. This value is close to the site-specific soil invertebrate BCF of about 0.3 that can be estimated from information reported in the Thiel et al. (1988) study.

For robins, the model predicts TCDD egg concentrations ranging from 8 ppt to 170 ppt, with a best estimate of 61 ppt. The higher end of this range is closer to the robin egg concentration values reported by Thiel et al. (1988), 120-162 ppt TCDD. The "high" estimate of wildlife exposure assumes that 100 percent of the robin's diet originates from sludge amended land. Thiel et al. (1988) remarked that there was an abundance of earthworms in the sludge treatment area. Therefore, the assumption that an individual robin obtains all of its food from the treated area may be reasonable at this site.

The wildlife exposure model predicts the TCDF concentration in bluebird eggs to range from 9.7 to 340 ppt, and predicts the TCDF concentration in robin eggs to range from 22 to 440 ppt. These values are much higher than those are reported in Thiel et al. (1988), despite the fact that the model assumes a rapid rate of metabolism for TCDF, as suggested by Martin et al., 1987. Even the low model estimates of the TCDF bluebird and robin egg concentrations are about four times higher than the average of the field study values. These results suggest that the metabolism of TCDF is even more rapid than already assumed, or that the bioconcentration factors for TCDF are different than those for TCDD, contrary to the assumption made in the model.

---

[3] However, the values presented in Thiel et al. (1988) cannot be directly compared to the estimated egg concentrations for bluebirds and robins derived in the present analysis, because the sludge concentrations assumed in the two analyses differ.

The comparison of model estimates to results of field studies shows good agreement on general conclusions regarding risks to wildlife at the Wisconsin land application site. The model seems to serve well as a general indicator of potential risk. However, to obtain more accurate numerical predictions of egg concentrations or other measures of wildlife risks, more site-specific information (such as site-specific bioconcentration factors and wildlife food mixes), as well as more information on the uptake and metabolism of TCDF, would be needed.

REFERENCES FOR CHAPTER 3

Bent, Arthur Cleveland (1955). Life Histories of North American Wagtails, Shrikes, Vireos, and Their Allies. New York: Dover Publications.

Bent, Arthur Cleveland (1962). Life Histories of North American Shore Birds, part 1. New York: Dover Publications.

Bent, Arthur Cleveland (1963a). Life Histories of North American Flycatchers, Larks, Swallows, and Their Allies. New York: Dover Publications.

Bent, Arthur Cleveland (1963b). Life Histories of North American Wood Warblers, parts 1 and 2. New York: Dover Publications.

Bent, Arthur Cleveland (1964). Life Histories of North American Thrushes, Kinglets, and Their Allies, parts 1 and 2. New York: Dover Publications.

Brewster, D.W., Matsumura, F., and T. Akera (1987). Effects of 2,3,7,8-tetrachloro-dibenzo-p-dioxin on guinea pig heart muscle. Toxicology and Applied Pharmacology 89: 408-417.

Caras, R.A. (1967). North American Mammals: Fur-bearing Animals of the United States and Canada. New York: Galahad Books.

Chapman, J.A., and G.A. Feldhamer, editors (1982). Wild Mammals of North America, Johns Hopkins University Press.

Davis, D.E. and F.B. Golly (1963). Principles of Mammology, Reinhold Publishing Company, 1963.

Dunning, J.B., Jr (1984). Body Weights of 686 Species of North American Birds. Western Bird Banding Association Monograph Number 1, May.

Eisler, R (1986). "Dioxin Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review." U.S. Department of the Interior, Fish and Wildlife Service, Biological Report 85 (1.8), May.

Food and Drug Administration (1989). "Bioavailability of Ingested 2,3,7,8-TCDD and Related Substances," draft memo dated June 22 from Ivan Boyer.

Hamilton, W.J. (1979). Mammals of the Eastern United States, Cornell University Press.

Hebert, C.D. and L.S. Birnbaum (1987). The influence of aging on intestinal absorption of TCDD in rats. Toxicology Letters 37:47-55.

Keenan, R.E (1986). Testimony before the Maine Bureau of Environmental Protection, March 16, 1986. In: Paper Industry Information Office. Potential Impacts on Wildlife from Dioxin Containing Sludges: A Compilation of Testimony and Exhibits from the BEP Hearing Record, (3/16/86 to date).

Keenan, R.E., Sauer, M., Lawrence, F., Rand, E., and D. Crawford (1989). "Examination of potential risks from exposure to dioxin in sludge used to reclaim abandoned strip mines." In: The Risk Assessment of Environmental and Human Health Hazards: A Textbook of Case Studies. D.J. Paustenbach, ed. J. Wiley and Sons, New York, pp. 935-998.

Kenaga, E.E.(1973). "Factors to be considered in the evaluation of the toxicity of pesticides to birds in their environment." In: Coulston, F., and F. Korte, editors. Environmental Quality and Safety: Global Aspects of Chemistry, Toxicology and Technology as Applied to the Environment. Academic Press.

Kenaga, E.E., and L.A. Norris (1983). "Environmental Toxicity of TCDD." In: Tucker, R.E., A.L. Young, and A.G. Gray, editors. Human and Environmental Risks of Chlorinated Dioxins and Related Compounds, Plenum Press, New York.

Kociba, R.J. and B.A. Schwetz (1982). Toxicity of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD). Drug Metabolism Reviews 13(3): 387-406.

Martin, S.G., Thiel, D.A., Duncan, J.W., and W.R. Lance (1987). "Effects of a paper industry sludge containing dioxin on wildlife in red pine plantations." In: Proceedings of 1987 TAPPI Environmental Conference.

Miller, R., Norris, L., and C. Hawkes (1973). Toxicity of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) in aquatic organisms. Environmental Health Perspectives, September, pp. 177-186.

Newton, M. and S. P. Snyder (1978). Exposure of forest herbivores to 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) in areas sprayed with 2,4,5-T. Bull. Environm. Contam. Toxicol. 20: 743-750.

Nikolaidis, E. Brunstrom, B., and L. Dencker (1988). Effects of TCDD and its congeners 3,3,4,4-tetrachlorazoxybenzene and 3,3,4,4,-tetrachlorobiphenyl on lymphoid development in the thymus of avian embryos. Pharmacology and Toxicology 63:333-336.

Ontario Ministry of the Environment, Intergovernmental Relations and Hazardous Contaminants Coordination Branch (1985). Scientific Criteria Document for Standard Development No. 4-84: Polychlorinated Dibenzo-p-dioxins (PCDDs) and Dibenzofurans (PCDFs). September.

Schonwetter, M. (1960-1983). Handbuch der Oologie. Berlin.

Schwetz, B.A., Norris, J.M., Sparschu, G.L., Rowe, V.K., Gehring, P.J., Emerson, J.L., and C.G. Gerbig (1973). Toxicology of chlorinated diobenzo-p-dioxins. Environmental Health Perspectives, September, pp. 87-99.

Sheldon, W.G.(1967). The Book of the American Woodcock, University of Massachusetts University Press.

Sullivan, J.R., Kubiak, T.J., Amundson, T. E., Martini, R. E., Olson, L. J., and G.A. Hill (1987). "A wildlife exposure assessment for landspread sludges which contain dioxins and furans." In: Proceedings of the Tenth Annual Madison International Waste Conference: Municipal and Industrial Waste. September 29-30, 1987. University of Madison, Madison, Wisconsin.

Thalken, C.E. and A.L. Young (1983). "Long-term field studies of a rodent population continuously exposed to TCDD." In: Tucker, R.E., Young, A.L. and A.P. Gray, editors. Human and Environmental Risks of Chlorinated Dioxins and Related Compounds, Plenum Publishing Corp.

Thiel, D. A., Martin, S.G., Duncan, J.W., Lemke, M.J., Lance, W.R. and R. Peterson (1988). "Evaluation of the effects of dioxin-contaminated sludges on wild birds." In: Proceedings of the 1988 TAPPI Environmental Conference.

U.S. EPA (1988). Office of Health and Environmental Assessment, Exposure Assessment Group. Estimating Exposure to 2,3,7,8-TCDD. Draft Report March.

U.S. EPA (1989a). Memorandum to Dioxin-in-Paper Workgroup, dated July 21 from C. Cinalli.

U.S. EPA (1989b). Memorandum to Dioxin-in-Paper Workgroup, on the bioavailability of dioxins in paper products, dated June 23 from C. Cinalli and Conrad Flessner.

U. S. EPA (1989c). "Memorandum: OTS/EEB Aquatic Life Hazard Assessment (Including BCF Values) for 'Dioxin in Paper'." Office of Pesticides and Toxic Substances. Washington, D.C. July.

U.S. EPA (1989d). 104-Mill Data Base. Office of Water Regulations and Standards, July 17 version.

Wipf, H.K., E. Homberger, N. Neuner, U.B. Ranalder, W. Vetter, and J.P. Vuilleumier (1982). "TCDD levels in soil and plant samples from the Seveso area." In: Huntiziger, O., R.W. Frei, E. Merian, and F. Pocchiari, editors. Chlorinated Dioxins and Related Compounds: Impact on the Environment, Pergamon Press, New York.

Young, A.L. (1983). "Long-term studies on the persistence and movement of TCDD in a natural ecosystem." In: Tucker, R.E., A.L. Young, and A.G. Gray, editors. Human and Environmental Risks of Chlorinated Dioxins and Related Compounds, Plenum Press, New York.

Young, A.L. (1984). "A case study in ecotoxicology: long-term field exposure of Peromysus Polionotus to dioxin." In: Hommage au Professor Rene Truhaut. Academie des Sciences, Paris, France, pp.1229-1233.

Young, A.L., and L. G. Cockerham (1985). "Fate of TCDD in field ecosystems - assessment and significance for human exposures." In: Kamrin, M.A., and P.W. Rodgers. Dioxins in the Environment. Hemosphere Publishing Corp., New York, pp. 153-171.

4.0 Analysis of Uncertainty

As explained in Chapter 1 of this report, this analysis attempts to quantify the uncertainty implicit in its exposure and risk estimates. To do so, it performs three separate model calculations of aggregate population risk for each waste disposal method and exposure pathway. The first set of calculations uses "best estimates" for each key input parameter, and yields "best estimates" of exposure and risk. Results from these calculations were presented in Chapters 2 and 3 of this report. In addition to these "best estimate" calculations, the analysis has repeated the calculations using assumptions and input parameter values thought to represent plausible "low risk" extremes for each parameter. By combining these "low risk" input values into a single scenario, it derives estimates of exposure and risk unlikely to over-estimate actual values[1]. Corresponding exposure and risk estimates have been prepared by combining "high risk" parameter values, where available, for each key input used for the model calculations. Results from "high risk" calculations are intended to represent upper bound estimates of exposure and risk, so that actual, "true" exposure and risk are unlikely to exceed the estimated values.

Table 4.A shows the range of estimates of total population risk derived for each waste management practice and exposure pathway considered. As can be seen from the Table, the "low risk" and "high risk" estimates differ by as much as three to four orders of magnitude for some exposure pathways. These results highlight the fact that this analysis is limited by data availability to "screening" analyses of exposure and risk. With more detailed, site-specific data for each waste use or disposal site, these ranges of uncertainty could be narrowed considerably. It should be noted that all risk estimates reported in Table 4.A are based on the same assumed human cancer potencies for TCDD and TCDF. The exact slope factor of these chemicals is itself uncertain; testing the range of possible values for slope factor would widen the range of risk estimates still further.

Total risk estimates for ingestion of contaminated groundwater were prepared for the disposal of sludge in landfills, disposal of sludge in surface impoundments, and the land application of sludge. For landfills and surface impoundments, risk estimates varied by one to two orders of magnitude. Results varied significantly between calculations involving the SESOIL model and those based on simpler, but less data intensive, assumptions about the equilibrium partitioning of contaminants between dissolved and adsorbed phase. "Low risk" estimates were not prepared, but estimates of zero risk through this pathway could be easily derived if landfills are assumed to be located in areas without productive aquifers.

---

[1] Even "low risk" estimates are based on upper-bound human cancer potency slopes, however. Actual cancer risks may be lower, or even zero.

Table 4.A Range of Estimates for Total Cancer Risks

Exposure pathway	Low risk estimate (cases/yr)	Best estimate (cases/yr)	High risk estimate (cases/yr)
Sludge Landfills			
Inhalation of vapor	not estimated	2×10^{-7}	3×10^{-3}
Ingestion of ground water	2×10^{-8}	4×10^{-8}	6×10^{-5}
Ingestion of surface water	1×10^{-3}	5×10^{-3}	6×10^{-1}
Ingestion of fish	1×10^{-3}	1×10^{-3}	4×10^{0}
Ingestion of sport fish	not estimated	4×10^{-4}	4×10^{-1}
Paper in Municipal Landfills			
Inhalation of vapor	not estimated	not estimated	not estimated
Ingestion of ground water	not estimated	not estimated	not estimated
Sludge Surface Impoundments			
Inhalation of vapor	not estimated	2×10^{-2}	3×10^{-1}
Ingestion of ground water	2×10^{-8}	1×10^{-7}	6×10^{-6}
Ingestion of surface water	2×10^{-3}	8×10^{-3}	1×10^{0}
Ingestion of fish	2×10^{-3}	3×10^{-3}	$1 \times 10^{+1}$
Ingestion of sport fish	not estimated	9×10^{-4}	1×10^{0}
Land Application of Sludge			
Dermal absorption	7×10^{-9}	2×10^{-6}	6×10^{-5}
Direct ingestion	4×10^{-8}	2×10^{-7}	5×10^{-5}
Inhalation of vapor	1×10^{-6}	4×10^{-6}	1×10^{-5}
Inhalation of particulates	5×10^{-7}	2×10^{-6}	6×10^{-6}
Ingestion of surface water	4×10^{-4}	2×10^{-3}	9×10^{-2}
Ingestion of ground water	not estimated	not estimated	not estimated
Ingestion of fish	1×10^{-3}	4×10^{-3}	6×10^{0}
Ingestion of sport fish	not estimated	1×10^{-3}	7×10^{-1}
Ingestion of produce	3×10^{-3}	7×10^{-2}	2×10^{-1}
Distribution and Marketing of Sludge			
Dermal absorption	3×10^{-6}	7×10^{-4}	4×10^{-1}
Direct ingestion	2×10^{-5}	3×10^{-3}	4×10^{-1}
Inhalation of vapor	5×10^{-5}	2×10^{-3}	5×10^{-3}
Inhalation of particulates	1×10^{-6}	5×10^{-5}	1×10^{-3}
Ingestion of produce	2×10^{-10}	8×10^{-7}	2×10^{-4}

Total risks from inhalation of particulates were estimated for persons living on a land application site, or applying pulp and paper sludge to home gardens. The estimated range of uncertainty is relatively low for these estimates (one to two orders of magnitude), and reflects differences in results based on different mathematical models for estimating particulate suspension. Other key variables are the ratio of indoor to outdoor concentrations, and assumed absorption rates in the lungs and gastrointestinal tract.

Risk estimates for inhalation of volatilized TCDD and TCDF are also relatively stable with respect to the assumptions tested for land application and distribution and marketing scenarios, and represent variation in assumptions about time spent indoors and outdoors, ratios between indoor and outdoor concentrations, and the fraction of organic carbon in the soil. For landfills, the wider range of estimates for exposure and risks from volatilized contaminants reflects the testing of two different models for estimating volatile emissions from soil. Both "best estimate" and "high risk" estimates of emissions from surface impoundments were based on a two film resistance model; differences in risk estimates are therefore attributable to differences in selected parameter values.

Precise estimation of total risks from ingestion of surface water contaminated by runoff from sludge use or disposal would require extensive, site-specific data for each sludge management site. Without detailed data about the location of each site, distances to surface water, site and surrounding topography, hydrology of nearby surface water, locations (if any) of withdrawal of surface water for drinking water sources, and numerous other key data, one must rely on simple screening models to derive rough estimates of potential risk. The wide range of risk estimates reported for this exposure pathway highlights the fact that without such site-specific data, precise quantification is impossible. As can be seen from the tables, the possibility of significant risks through this pathway cannot be ruled out on the basis of existing data. Risk estimates are sensitive to the size of the drainage area assumed for the stream receiving runoff from each site.

Similarly, precise estimation of total risk from fish ingestion is impossible without detailed, site-specific information. Depending on the assumptions chosen for modeling exposure and risks through this pathway, resulting estimates can vary by four orders of magnitude or more. As with risks from the ingestion of drinking water from surface water sources contaminated by surface runoff, significant risks from ingestion of fish cannot be dismissed on the basis of this analysis.

Total risks from dietary consumption of vegetables, meat or dairy products grown from sludge amended land (or from feeds grown on sludge-amended land) vary by about two orders of magnitude for land application sites, depending on the assumptions chosen. Key assumptions include the percentage of the animal's diet consisting of sludge, and bioconcentration factors. For distribution and marketing, dietary risk estimates vary by four orders of magnitude, depending on which set of assumptions is used. Results are greatly influenced by whether the analysis assumes soil incorporation, and by the fraction of each household's diet assumed to be home-grown.

Estimated total risks from dermal absorption of TCDD and TCDF in sludge or soil are also subject to the selection of parameter values; "low risk" and "high risk" estimates differ by as much as four orders of magnitude. This range is attributable to numerous differences in the two scenarios, including whether or not the sludge is assumed to be soil incorporated, the area of skin exposed, contact rates and absorption rates for skin, and other factors. Estimated total risks from direct ingestion of soil vary by two to three orders of magnitude, depending on whether the sludge is assumed to be soil incorporated, assumed rates of soil ingestion for children and adults, and the fraction of daily soil ingestion originating from the treated area.

Tables 4.B through 4.U provide more detailed results from the uncertainty analysis performed for this report. Tables 4.B through 4.F report exposure estimates derived from "low risk" assumptions and parameter values, and Tables 4.G through 4.K report the corresponding estimates of risk. Similarly, Tables 4.L through 4.P report exposure estimates derived from "high risk" assumptions and parameters, and Tables 4.Q through 4.U report corresponding risk estimates. For some waste management practices and exposure pathways, exposure and risk estimates for the MEI have also been tested for sensitivity to key assumptions; results are listed in Tables 4.B through 4.U.

Tables 4.V through 4.X summarize the "low risk" estimates for birds, bird eggs, and mammals. Each of these tables shows the lowest and highest dose (expressed as a percent of the LOAEL) estimated among the seven land application sites evaluated. Tables 4.Y through 4.AA present the "high risk" estimates for wildlife species.

The differences between "low risk" and "high risk" estimates are largely attributable to differences in bioconcentration factors of prey items. For birds that are mainly insectivorous, the "high risk" estimate is approximately an order of magnitude higher than the "low risk" estimate. The difference is due primarily to a three-fold variation in the bioconcentration factor for insects between the "low risk" and "high risk" scenarios. Risk estimates for woodcocks vary by over two orders of magnitude. The woodcock diet is assumed to consist of 100% earthworms for the purposes of this analysis; the difference in the woodcock risk estimates is largely attributable to the factor of 50 difference between low and high estimates of the bioconcentration factor for earthworms. Similarly, moles and shrews have large differences between "low risk" and "high risk" estimates because a large fraction of the diets of these species consists of earthworms. Differences between

Table 4.8. Low Estimate of Human Exposure from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed:	1×10^{-14}	(<0.01)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed:	3×10^{-14}	(0.5)	3×10^{-16}	(7)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed:	4×10^{-8}	(0.2)	4×10^{-13}	(0.4)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed:	6×10^{-9}	(22)	2×10^{-13}	(43)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$

[d] Not Applicable

Table 4.C. Low Estimate of Human Exposure from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed:	$<2 \times 10^{-12}$	(17)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed:	1×10^{-15}	(50)	NA[d]	NA[d]

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as:
$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

[d] Not applicable

Table 4.D. Low Estimate of Human Exposure from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed:	9×10^{-11}	(0.8)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed:	2×10^{-12}	(0.5)	3×10^{-15}	(1.3)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed:	2×10^{-7}	(0.8)	2×10^{-12}	(0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	6×10^{-8}	(59)	2×10^{-12}	(60)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$$

[d] Not Applicable

Table 4.E. Low Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Dermal exposure from contact with soil contaminated by land application of sludge:	6×10^{-10}	(>99)	4×10^{-14}	(>99)
Exposure from direct ingestion of soil contaminated by land application of sludge:	2×10^{-9}	(>99)	3×10^{-13}	(>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge:	7×10^{-11}	(>99)	8×10^{-12}	(>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge:	2×10^{-11}	(>99)	3×10^{-12}	(>99)

Table 4.E (cont.). Low Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge:	2×10^{-9}	(26)	3×10^{-13}	(2)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (0.2)	$<2 \times 10^{-12}$	(0.2)	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by land application of sludge:	1×10^{-8}	(98)	4×10^{-13}	(76)
Dietary exposure from produce grown in soil contaminated by land application of sludge:	7×10^{-8}	(>99)	4×10^{-15}	(>99)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

[d] Not applicable

Table 4.F. Low Estimate of Human Exposure from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)	Typical exposure[a] (mg/kg/day)	(% TCDD)
Dermal exposure from contact with soil contaminated by distributed and marketed sludge:	3×10^{-10}	(35)	2×10^{-16}	(38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge:	8×10^{-10}	(35)	1×10^{-15}	(38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge:	3×10^{-12}	(1)	4×10^{-15}	(2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge:	4×10^{-13}	(35)	8×10^{-17}	(38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge:	5×10^{-14}	(35)	1×10^{-20}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

Table 4.G. Low Estimate of Human Health Risk from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI risk^a (per lifetime)	Typical risk^a (per lifetime)	Exposed population	Total risk (cases/year)^b
Inhalation exposure from volatilization from landfills in which sludge is disposed: (Percent TCDD)^c	3×10^{-9} (<0.1)	NA^d	NA^d	NA^d
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed: (Percent TCDD)^c	8×10^{-9} (0.6)	9×10^{-11} (7)	13,125	2×10^{-8} (7)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed: (Percent TCDD)^c	1×10^{-2} (0.2)	1×10^{-7} (0.4)	698,200	1×10^{-3} (0.4)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed: (Percent TCDD)^c	2×10^{-3} (22)	5×10^{-8} (43)	1,424,900	1×10^{-3} (43)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 4.N. Low Estimate of Human Health Risk from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<7 \times 10^{-7}$ (17)	NA$_d$	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed: (Percent TCDD)[c]	3×10^{-10} (50)	NA[d]	NA[d]	NA[d]

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

Table 4.1. Low Estimate of Human Health Risk from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-5} (0.8)	NA[d]	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-7} (0.5)	8×10^{-10} (1.3)	2,000	2×10^{-8} (1.3)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-2} (0.8)	5×10^{-7} (0.8)	195,400	2×10^{-3} (0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-2} (59)	4×10^{-7} (60)	398,692	2×10^{-3} (60)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not Applicable

Table 4.J. Low Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

EXPOSURE PATHWAY	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (>99)	1×10^{-8} (>99)	40	7×10^{-9} (>99)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-4} (>99)	8×10^{-8} (>99)	40	4×10^{-8} (>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-5} (>99)	2×10^{-6} (>99)	40	1×10^{-6} (>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	5×10^{-6} (>99)	9×10^{-7} (>99)	40	5×10^{-7} (>99)

Table 4.J (cont.). Low Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge: (Percent TCDD)[c]	6×10^{-4} (26)	9×10^{-8} (2)	298,000	4×10^{-4} (2)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c]	$<6 \times 10^{-7}$ (0.2)	NA[d]	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-3} (98)	1×10^{-7} (77)	610,000	1×10^{-3} (77)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-2} (>99)	1×10^{-9} (>99)	240,000,000	3×10^{-3} (>99)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

[d] Not applicable

Table 4.K. Low Estimate of Human Health Risk from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	8×10^{-5} (35)	5×10^{-11} (38)	3,500,00	3×10^{-6} (38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-4} (35)	4×10^{-10} (38)	3,500,000	2×10^{-5} (38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	8×10^{-7} (1)	1×10^{-9} (2)	3,500,000	5×10^{-5} (2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-7} (35)	2×10^{-11} (38)	3,500,000	1×10^{-6} (38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-8} (35)	4×10^{-15} (38)	3,500,000	2×10^{-10} (38)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table 4.L. High Estimate of Human Exposure from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed:	1×10^{-11}	(0.9)	6×10^{-14}	(0.9)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed:	1×10^{-11}	(0.2)	3×10^{-13}	(2)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed:	4×10^{-8}	(0.2)	2×10^{-11}	(0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed:	2×10^{-7}	(31)	7×10^{-11}	(54)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from landfills in which sludge is disposed:	2×10^{-7}	(31)	2×10^{-10}	(54)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 4.N. High Estimate of Human Exposure from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed:	$<2 \times 10^{-12}$	(17)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed:	1×10^{-15}	(50)	NA[d]	NA[d]

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \dfrac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$

[d] Not applicable

Table 4.M. High Estimate of Human Exposure from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed:	1×10^{-9}	(1)	9×10^{-12}	(0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed:	2×10^{-12}	(0.2)	2×10^{-13}	(1)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed:	2×10^{-7}	(0.8)	1×10^{-10}	(2)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	3×10^{-6}	(70)	6×10^{-10}	(71)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	3×10^{-6}	(70)	2×10^{-9}	(71)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 4.0. High Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Dermal exposure from contact with soil contaminated by land application of sludge:	6×10^{-10}	(>99)	4×10^{-10}	(>99)
Exposure from direct ingestion of soil contaminated by land application of sludge:	2×10^{-9}	(>99)	3×10^{-10}	(>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge:	9×10^{-11}	(>99)	9×10^{-11}	(>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge:	5×10^{-11}	(>99)	4×10^{-11}	(>99)

Table 4.0. (cont.). High Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge:	4×10^{-9}	(13)	8×10^{-12}	(16)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge:	$<2 \times 10^{-12}$	(0.2)	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by land application of sludge:	7×10^{-7}	(98)	3×10^{-10}	(98)
Ingestion exposure to fish caught by recreational fishing in surface runoff areas contaminated by land application of sludge:	7×10^{-7}	(>99)	8×10^{-10}	(98)
Dietary exposure from produce grown in soil contaminated by land application of sludge:	1×10^{-7}	(>99)	2×10^{-13}	(>99)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not Applicable

Table 4.P. High Estimate of Human Exposure from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)	Typical exposure[a] (mg/kg/day)	(% TCDD)
Dermal exposure from contact with soil contaminated by distributed and marketed sludge:	3×10^{-10}	(35)	1×10^{-10}	(38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge:	8×10^{-10}	(35)	9×10^{-11}	(38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge:	4×10^{-12}	(1)	1×10^{-12}	(2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge:	9×10^{-13}	(35)	2×10^{-13}	(38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge:	1×10^{-13}	(35)	4×10^{-14}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 4.Q. High Estimate of Human Health Risk from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed: (Percent TCDD)[c]	3×10^{-6} (0.9)	2×10^{-8} (0.9)	12,800,000	3×10^{-3} (0.9)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed: (Percent TCDD)[c]	4×10^{-6} (0.2)	9×10^{-8} (2)	52,500	6×10^{-5} (2)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	1×10^{-2} (0.2)	7×10^{-6} (0.8)	6,982,000	6×10^{-1} (0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	6×10^{-2} (31)	2×10^{-5} (54)	14,200,000	4×10^{0} (54)
Ingestion exposure from fish caught by recreational fishing in surface water from landfills in which sludge is disposed: (Percent TCDD)[c]	6×10^{-2} (31)	5×10^{-5} (54)	527,000	4×10^{-1} (54)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 4.R. High Estimate of Human Health Risk from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<7 \times 10^{-7}$ (17)	NA[d]	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed: (Percent TCDD)[c]	3×10^{-10} (50)	NA[d]	NA[d]	NA[d]

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

[d] Not applicable

Table 4.5. High Estimate of Health Risk from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-4} (1)	3×10^{-6} (0.8)	7,100,000	3×10^{-1} (0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-7} (0.2)	6×10^{-8} (1)	8,000	6×10^{-6} (1)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-2} (0.8)	4×10^{-5} (2)	1,950,000	1×10^{0} (2)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	8×10^{-1} (70)	2×10^{-4} (71)	4,000,000	1×10^{1} (71)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	8×10^{-1} (70)	5×10^{-4} (71)	147,000	1×10^{-0} (71)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 4.T. High Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (>99)	1×10^{-4} (>99)	40	6×10^{-5} (>99)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-4} (>99)	9×10^{-5} (>99)	40	5×10^{-5} (>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-5} (>99)	2×10^{-5} (>99)	40	1×10^{-5} (>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-5} (>99)	1×10^{-5} (>99)	40	6×10^{-6} (>99)

Table 4.T (cont). High Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-3} (13)	2×10^{-6} (16)	2,780,000	9×10^{-2} (16)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c](0.2)	$<6 \times 10^{-7}$ (0.2)	NA[d]	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-1} (98)	7×10^{-5} (98)	6,100,000	6×10^{0} (98)
Ingestion exposure to fish caught by recreational fishing in surface runoff from areas contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-1} (98)	2×10^{-4} (98)	224,000	7×10^{-1} (98)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	3×10^{-2} (>99)	5×10^{-8} (>99)	240,000,000	2×10^{-1} (>99)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

[d] Not applicable

Table 4.U. High Estimate of Human Health Risk from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	8×10^{-5} (35)	3×10^{-5} (38)	1,060,000	4×10^{-1} (38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-4} (35)	2×10^{-5} (38)	1,060,000	4×10^{-1} (38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-6} (1)	3×10^{-7} (2)	1,060,000	5×10^{-3} (2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-7} (35)	6×10^{-8} (38)	1,060,000	1×10^{-3} (38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)[c]	3×10^{-8} (35)	1×10^{-8} (38)	1,060,000	2×10^{-4} (38)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 4.V. Summary of Risks to Birds ("Low Risk" Scenario)

Species	Lowest Value for Dose as a Percent of NOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of NOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	0	0	PA, ME	53	29	OH
American Robin	0	0	PA, ME, MS (TCDF)	67	18	GA
Great Crested Flycatcher	0	0	PA, MS (TCDF)	56	16	GA
Loggerhead Shrike	0	0	PA, MS (TCDF)	128	70	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	28	15	OH
Tree Swallow	0	0	ME	57	16	GA
Pine Warbler	0	0	ME	82	23	GA
Woodcock	0	0	ME	68	19	GA
Woodthrush	0	0	ME	33	9	GA

Table 4.W. Summary of Risks to Bird Eggs ("Low Risk" Scenario)

Species	Lowest Value for Concentration as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Concentration as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	0	0	PA, ME	49	5	OH
American Robin	0	0	PA, MS (TCDF), ME (TCDF)	136	6	GA
Great Crested Flycatcher	0	0	PA, MS (TCDF)	85	4	GA
Loggerhead Shrike	0	0	PA, MS (TCDF)	163	11	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	53	5	OH
Tree Swallow	1	0	ME	112	5	GA
Pine Warbler	1	0	ME	92	4	GA
Woodcock	1	0	ME	136	7	GA
Woodthrush	0	0	ME	55	3	GA

Table 4.X. Summary of Risks to Mammals ("Low Risk" Scenario)

Species	Lowest Value for Dose as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Nine-banded Armadillo (1)	11	0	MS	11	0	MS
Grey Bat	0	0	PA, MS (TCDF)	362	100	GA
Eastern Mole	0	0	PA, MS (TCDF), ME (TCDF)	122	32	GA
River Otter	0	0	(2)	0	0	(2)
Virginia Opossum	0	0	PA, ME, MS (TCDF)	72	20	GA
Least Shrew	0	0	PA, MS (TCDF)	299	83	GA
Striped Skunk	0	0	PA, ME, MS (TCDF)	38	11	GA

(1) Armadillo only occurs in Mississippi

(2) River otter dose less than 0.5% in all states

Table 4.Y. Summary of Risks to Birds ("High Risk" Scenario)

Species	Lowest Value for Dose as a Percent of NOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of NOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	1	0	PA	472	259	OH
American Robin	1	0	PA, MS (TCDF)	657	182	GA
Great Crested Flycatcher	1	0	PA, MS (TCDF)	493	136	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	685	375	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	242	133	OH
Tree Swallow	3	1	ME	505	140	GA
Pine Warbler	4	2	ME	715	198	GA
Woodcock	44	198	ME	7889	2184	GA
Woodthrush	2	1	ME	298	82	GA

Table 4.2. Summary of Risks to Bird Eggs ("High Risk" Scenario)

Species	Lowest Value for Concentration as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Concentration as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	3	0	PA	1847	160	OH
American Robin	4	0	PA, MS (TCDF)	3016	132	GA
Great Crested Flycatcher	2	0	PA, MS (TCDF)	1680	73	GA
Loggerhead Shrike	2	0	PA, MS (TCDF)	1429	124	OH
Eastern Meadowlark	2	0	PA, MS (TCDF)	1034	90	OH
Tree Swallow	12	1	ME	2219	97	GA
Pine Warbler	10	1	ME	1826	80	GA
Woodcock	198	16	ME	35832	1567	GA
Woodthrush	6	0	ME	1115	49	GA

Table 4.A.A. Summary of Risks to Mammals ("High Risk" Scenario)

Species	Lowest Value for Dose as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Nine-banded Armadillo (1)	37	0	MS	37	0	MS
Grey Bat	3	0	PA	2715	752	GA
Eastern Mole	5	0	PA	3850	1066	GA
River Otter	0	0	(2)	6	2	GA
Virginia Opossum	1	0	PA	469	130	GA
Least Shrew	14	0	PA	11448	3169	GA
Striped Skunk	0	0	PA	289	80	GA

(1) Armadillo only occurs in Mississippi

(2) River otter dose less than 0.5% in PA, ME, WI, MS

the risk estimates are smallest for loggerhead shrikes, opossums, and skunks. For all of these species, small mammals constitute a sizeable portion of the diet; the relatively small difference in the "low risk" and "high risk" estimates is in part attributable to small variation in the low and high values assumed for the small mammal biconcentration factor.

Differences in risk estimates are also attributable to differences in the high and low values used for other parameters besides bioconcentration factors. In the "high risk" scenario, birds and mammals obtain all of their food from the treated area, while in the "low risk" scenario, only half of their food originates in the treated area, leading to a factor of two differences between the scenarios. Differences in the absorption rate for food also contribute to the difference between "low risk" and "high risk" estimates.

Differences in the "low risk" and "high risk" estimates for bird egg risks range from a factor of 10 to a factor of 240. The estimates vary for the reasons described above and because of differences in the half-life of TCDD and TCDF assumed in the "low risk" and "high risk" scenarios. Differences in the risk estimates for bird eggs are also influenced by the differences in the length of time the female bird is assumed to reside on-site before laying.

Evident from Tables 4.A to 4.AA is the considerable uncertainty implicit in the risk estimates derived by this report. In the absence of detailed site-specific data for the numerous sites at which sludge is used or disposed, such broad ranges of uncertainty in exposure and risk estimates are unavoidable.

5.0 Conclusions

Table 5.A compares human health risk estimates for each waste disposal method analyzed under current use and disposal practices. For each waste management practice, it reports results for the exposure pathway found to result in highest risks to the "most exposed individual" and to the total population. The possibility of simultaneous exposure through multiple pathways is ignored. By comparing maximum estimated risks for each management practice, Table 5.A allows a simple comparison of risks associated with each practice.

As can be seen from the table, estimated risks to a "most exposed individual" are lowest for the landfilling of paper wastes, and highest for sludge surface impoundments and land application. Estimated risks to typical exposed individuals are generally three to six orders of magnitude lower than risks to the MEI, except for the landfilling of paper wastes, for which separate population risk estimates were not performed. The largest exposed population is associated with the land application of sludge, since foods grown with sludge-amended land may enter national food distribution systems and be consumed by the entire U.S. population. As shown by the table, none of the waste disposal methods and exposure pathways analyzed is expected to result in a total population cancer risk of more than one expected incremental cancer case per ten years of sludge or paper disposal.

Table 5.B reports maximum exposure to TCDD and TCDF for all pathways associated with each method of waste management considered in this analysis. As is evident from the table, estimated MEI exposure reaches as high as 10^{-8} mg/kg/day for sludge surface impoundments and land application.

Tables 5.C through 5.L provide more detail concerning estimated human exposure and cancer risk associated with each individual pathway of potential human exposure. Two tables are provided for each waste use or disposal practice considered in Sections 2.1 through 2.5. For each practice, the first table reports estimated exposure to both the MEI and typical exposed population for each pathway of potential exposure. The second table reports estimated risks for the "most exposed individual", estimated typical risks, the estimated size of the exposed population, and the estimated total cancer risks associated with the levels of exposure presented in the preceding table.

As can be seen from Tables 5.C and 5.D, exposure and risks to the "most exposed individual" from the landfilling of sludge are highest from pathways associated with surface runoff. Estimated risks through these pathways for the MEI are based on an extreme scenario in

Table 5.A. **Maximum Human Health Risks from Exposure to TCDD and TCDF, by Waste Management Method**

Exposure Pathway	MEI risk[a,b] (per lifetime)	Typical risk[a,c] (per lifetime)	Exposed population[d]	Total risk (cases/year)[e]
Potential human exposure from disposal of pulp and paper sludge in landfills (percent TCDD)[f]	2×10^{-3} (0.2)	5×10^{-8} (0.4)	6,982,000	5×10^{-3} (0.4)
Potential human exposure from disposal of paper wastes in landfills (percent TCDD)[f]	$<3 \times 10^{-10}$ (50)	not estimated	not estimated	not estimated
Potential human exposure from disposal of pulp and paper sludge in surface impoundments (percent TCDD)[f]	2×10^{-2} (59)	3×10^{-7} (0.8)	7,100,000	2×10^{-2} (0.8)
Human exposure from land application of pulp and paper sludge (percent TCDD)[f]	2×10^{-2} (>99)	7×10^{-6} (>99)	240,000,000	7×10^{-2} (>99)
Human exposure from distribution and marketing of pulp and paper sludge (percent TCDD)[f]	2×10^{-4} (98)	6×10^{-8} (38)	3,500,000	3×10^{-3} (2)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5 / 0.55

[b] Represents highest risk to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method. All risk estimates based on "best estimate" input parameters.

[c] Represents risk to average exposed individual for single exposure pathway associated with highest total risk for this waste disposal or re-use method. All risk estimates based on "best estimate" input parameters.

[d] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[e] Total exposed population for single exposure pathway associated with highest total risks for this sludge re-use or disposal method.

[f] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$

Table 5.8. Maximum Exposure to TCDD and TCDF by Waste Re-Use or Disposal Method

Exposure Pathway	MEI Exposure[a,b] (mg/kg/day)	(% TCDD)[c]	Typical Exposure[a,d] (mg/kg/day)	(% TCDD)[c]
Potential Human Exposure from Disposal of Pulp and Paper Sludge in Landfills	6×10^{-9}	(22)	2×10^{-13}	(0.4)
Potential Human Exposure from Disposal of Paper Wastes in Landfills	1×10^{-15}	(50)	1×10^{-15}	(50)
Potential Human Exposure from Disposal of Pulp and Paper Sludge in Surface Impoundments	7×10^{-8}	(59)	1×10^{-12}	(0.8)
Human Exposure from Land Application of Pulp and Paper Sludge	7×10^{-8}	(>99)	2×10^{-13}	(6)
Human Exposure from Distribution and Marketing of Pulp and Paper Sludge	8×10^{-10}	(35)	2×10^{-13}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + one tenth of estimated exposure to 2,3,7,8-TCDF.

[b] Represents highest exposure to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method. All exposure estimates based on "best estimate" input parameters.

[c] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

[d] Represents highest average exposure through any single exposure pathway associated with this waste disposal or re-use method. All exposure estimates based on "best estimate" input parameters.

Table 5.C. Best Estimate of Human Health Risk from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed: (Percent TCDD)[c]	3×10^{-9} (<0.1)	8×10^{-13} (<0.1)	12,800,000	2×10^{-7} (<0.1)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed: (Percent TCDD)[c]	8×10^{-9} (0.5)	1×10^{-10} (6)	23,810	4×10^{-8} (6)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	1×10^{-3} (0.2)	5×10^{-8} (0.4)	6,982,000	5×10^{-3} (0.4)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	2×10^{-3} (22)	7×10^{-9} (43)	14,200,000	1×10^{-3} (43)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from landfills in which sludge is disposed: (Percent TCDD)[c]	2×10^{-3} (22)	5×10^{-8} (43)	527,000	4×10^{-4} (43)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 5.D. Best Estimate of Human Exposure from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from landfills in which sludge is disposed:	1×10^{-14}	(<0.1)	3×10^{-18}	(<0.1)
Ingestion exposure from drinking groundwater contaminated by leachate from landfills in which sludge is disposed:	3×10^{-14}	(0.5)	4×10^{-16}	(6)
Ingestion exposure from drinking surface water contaminated by surface runoff from landfills in which sludge is disposed:	4×10^{-9}	(0.2)	2×10^{-13}	(0.4)
Ingestion exposure from fish caught in surface water contaminated by runoff from landfills in which sludge is disposed:	6×10^{-9}	(22)	3×10^{-14}	(43)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from landfills in which sludge is disposed:	6×10^{-9}	(22)	2×10^{-13}	(43)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table 5.E. Best Estimate of Human Exposure from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed:	$<4 \times 10^{-12}$	(16)	$<4 \times 10^{-12}$	(16)
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed:	$<6 \times 10^{-15}$	(53)	$<6 \times 10^{-15}$	(53)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 5.F. Best Estimate of Human Health Risk from Landfill Disposal of Paper Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<9 \times 10^{-7}$ (16)	$<9 \times 10^{-7}$ (16)	NA[d]	NA[d]
Ingestion exposure from drinking groundwater contaminated by leachate from municipal landfills in which paper is disposed: (Percent TCDD)[c]	$<2 \times 10^{-9}$ (53)	2×10^{-9} (53)	18,500,000	$<4 \times 10^{-4}$ (53)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

[d] Not applicable

Table 5.G. Best Estimate of Human Health Risk from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-5} (0.8)	2×10^{-7} (0.8)	7,100,000	2×10^{-2} (0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-7} (0.5)	2×10^{-9} (0.9)	4,074	1×10^{-7} (0.9)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	6×10^{-3} (0.8)	3×10^{-7} (0.8)	1,950,000	8×10^{-3} (0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-2} (59)	6×10^{-8} (60)	4,000,000	3×10^{-3} (60)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-2} (59)	4×10^{-7} (60)	147,000	9×10^{-4} (60)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \dfrac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 5.N. Best Estimate of Human Exposure from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed:	9×10^{-11}	(0.8)	6×10^{-13}	(0.8)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed:	2×10^{-12}	(0.5)	8×10^{-15}	(0.9)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed:	2×10^{-8}	(0.8)	1×10^{-12}	(0.8)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	7×10^{-8}	(59)	2×10^{-13}	(60)
Ingestion exposure from fish caught by recreational fishing in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	6×10^{-8}	(59)	2×10^{-12}	(60)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 5.1. Best Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (>99)	3×10^{-6} (>99)	40	2×10^{-6} (>99)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-4} (>99)	4×10^{-7} (>99)	40	2×10^{-7} (>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-5} (>99)	7×10^{-6} (>99)	40	4×10^{-6} (>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	5×10^{-6} (>99)	3×10^{-6} (>99)	40	2×10^{-6} (>99)

Table 5.I (con't.). Best Estimate of Human Health Risk from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-4} (13)	5×10^{-8} (6)	2,783,000	2×10^{-3} (6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c] (0.2)	$<6 \times 10^{-7}$ (0.2)	$<6 \times 10^{-7}$	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-3} (96)	5×10^{-8} (92)	6,100,000	4×10^{-3} (92)
Ingestion exposure to fish caught by recreational fishing in surface runoff areas contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-3} (96)	4×10^{-7} (92)	224,000	1×10^{-3} (92)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-2} (>99)	2×10^{-8} (>99)	240,000,000	7×10^{-2} (>99)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^{5} / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

[d] Not applicable

Table 5.J. Best Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Dermal exposure from contact with soil contaminated by land application of sludge:	6×10^{-10}	(>99)	1×10^{-11}	(>99)
Exposure from direct ingestion of soil contaminated by land application of sludge:	2×10^{-9}	(>99)	1×10^{-12}	(>99)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge:	7×10^{-11}	(>99)	3×10^{-11}	(>99)
Inhalation exposure to particulates from soil contaminated by land application of sludge:	2×10^{-11}	(>99)	1×10^{-11}	(>99)

Table 5.J (con't.). Best Estimate of Human Exposure from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge:	5×10^{-10}	(13)	2×10^{-13}	(6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge:	$<2 \times 10^{-12}$	(0.2)	$<2 \times 10^{-12}$	(0.2)
Ingestion exposure to fish caught in surface water contaminated by runoff from areas contaminated by land application of sludge:	1×10^{-8}	(97)	2×10^{-13}	(92)
Ingestion exposure to fish caught by recreational fishing in surface water contaminated by runoff from areas contaminated by land application of sludge:	1×10^{-8}	(97)	1×10^{-12}	(92)
Dietary exposure from produce grown in soil contaminated by land application of sludge:	7×10^{-8}	(>99)	7×10^{-14}	(>99)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 5.K. Best Estimate of Human Health Risk from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk^a (per lifetime)	Typical risk^a (per lifetime)	Exposed population	Total risk (cases/year)^b
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)^c	8×10^{-5} (35)	1×10^{-8} (38)	3,500,000	7×10^{-4} (38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)^c	2×10^{-4} (35)	6×10^{-8} (38)	3,500,000	3×10^{-3} (38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)^c	8×10^{-7} (1)	4×10^{-8} (2)	3,500,000	2×10^{-3} (2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)^c	1×10^{-7} (35)	1×10^{-9} (38)	3,500,000	5×10^{-5} (38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)^c	1×10^{-8} (35)	2×10^{-11} (38)	3,500,000	8×10^{-7} (38)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5 / 0.55

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$$

Table 5.L. Best Estimate of Human Exposure from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)	Typical exposure[a] (mg/kg/day)	(% TCDD)
Dermal exposure from contact with soil contaminated by distributed and marketed sludge:	3×10^{-10}	(35)	5×10^{-14}	(38)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge:	8×10^{-10}	(35)	2×10^{-13}	(38)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge:	3×10^{-12}	(1)	2×10^{-13}	(2)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge:	4×10^{-13}	(35)	4×10^{-15}	(38)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge:	5×10^{-14}	(35)	6×10^{-17}	(38)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

which runoff from the site reaches a stream of relatively small drainage area, and the MEI is assumed to take drinking water or fish from the most contaminanted segment of the stream. Typical risks through surface water pathways are estimated based on the assumption of larger drainage areas, and are considerably lower.

Tables 5.E and 5.F report estimated exposure and human health risks from the disposal of paper wastes in municipal landfills. Estimated exposure and risk reported in the tables for the MEI are based on consistently conservative assumptions chosen to provide upper bound risk estimates. TCDF is more easily volatilized from landfills than TCDD, and is responsible for most of the estimated risk through the volatilization pathway. Because estimated exposure and risk to the MEI were sufficiently low, no estimates of typical individual risk were attempted for the disposal of paper in municipal landfills.

Estimated exposure and risks from disposal of sludge in surface impoundments are presented in Tables 5.G and 5.H. As with landfills, estimated risks to the MEI from this sludge storage or disposal practice are dominated by pathways associated with surface runoff. These estimates are based on the assumption that the most exposed individual takes drinking water and fish from a relatively small stream and from the stream location with maximum dissolved concentrations of TCDD and TCDF.

Estimated risks from inhalation of volatilized contaminants from a surface impoundment are significantly higher than those estimated for landfills, since rates of contaminant emissions from an uncovered liquid impoundment surface are estimated to be much higher than those estimated from a landfill with soil cover. As with landfills, TCDF dominates risks through the volatilization pathway, because of its higher mobility. Estimated risks to typical exposed individuals are significantly lower than those estimated for the "most exposed individual." Highest typical individual risks are estimated for volatilization.

Tables 5.I and 5.J show estimated human exposure and health risks associated with the eight human exposure pathways evaluated for the land application of pulp and paper sludge. Highest MEI health risks from land application are encountered through the dietary exposure pathway. Risks through dietary pathways are calculated for two states in which pulp and paper sludge is applied to agricultural land: Mississippi and Pennsylvania. Mississippi's contribution to total risks outweighs that of Pennsylvania, because of the larger area of land treated in Mississippi. Since TCDF concentrations of zero were reported for sludge applied in Mississippi, TCDD dominates the risks to the MEI.

After the dietary exposure pathway, the next highest risk estimates for the MEI are found for exposure pathways associated with surface runoff. The next highest estimated risks are found for pathways involving direct human contact with contaminated soil: direct ingestion and dermal exposure.

Typical risks to exposed populations are low through all exposure pathways analyzed for land application; highest typical risks are estimated for persons living near a land application site and inhaling TCDD and TCDF vapor emitted by treated soil. Highest total risks are estimated for dietary pathways, due in part to the assumption that food from sludge-amended land is distributed nationally.

Estimated human exposure and risks from the distribution and marketing of pulp and paper sludge are presented in Tables 5.K and 5.L. These are based on the assumption that all of the sludge is used for vegetable or ornamental gardening in residential settings. Estimated risks to the "most exposed individual" are lowest for inhalation and dietary pathways, and highest for pathways involving direct human contact with sludge or soil. Risks to gardening individuals with more "typical" behaviors are two to three orders of magnitude lower than those estimated for the MEI

For many of the disposal options considered, the levels of exposure estimated are high enough to represent non-cancer risks as well as the cancer risks discussed above. The Wisconsin Department of Health and Social Services (1989), for example, reports a Risk Reference Dose (RfD) of about 2 picograms per day (pg/day) for behavioral toxic effects in humans, 70 pg/day for organ and reproductive toxicity, 2,000 pg/day for genetic toxicity, and 7,000 pg/day for acute toxicity. Based on an assumed average body weight of 70 kilograms, these values are equivalent to 3×10^{-11}, 1×10^{-9}, 3×10^{-8}, and 1×10^{-7} mg/kg/day, respectively. Although the Wisconsin RfDs do not represent EPA-reviewed values, they provide possible benchmarks against which the exposure estimates can be compared.

"Best estimates" of TCDD exposure[1] for a most exposed individual reach as high as 1×10^{-9} mg/kg/day for sludge landfills (thus reaching the RfD for organ and reproductive toxicity). MEI "best estimates" for surface impoundments reach as high as 4×10^{-8}, and exceed the genetic toxicity threshold. The highest "best estimate" of MEI exposure to TCDD from land application is 7×10^{-8} mg/kg/day, enough to exceed the genetic toxicity RfD. None of the exposure pathways evaluated for sludge distribution and marketing or for the landfilling of paper wastes exceeds these thresholds, nor do any of the TCDD exposure estimates derived for typical exposed populations.

---

[1] RfD values for TCDF were not available, so only TCDD exposure is considered for these comparisons.

Risks to wildlife were assessed for the land application of sludge; Tables 5.M through 5.O summarize results. Table 5.M presents a summary of risks to birds foraging from land application sites. This table shows the lowest and highest estimates of the daily dose (expressed as a percent of the "no observable adverse effects level" or NOAEL) among the seven land application sites assessed in this analysis. Similarly, Table 5.N summarizes the risks to bird eggs, while Table 5.O presents the risks to mammalian species. The tables show that those species whose diets consist largely of prey species that bioconcentrate TCDD and TCDF are at greatest risk from the land application of sludges containing TCDD and TCDF.

These results imply that individual members of certain wildlife species are at risk for reproductive and other effects from the land application of pulp and paper mill sludges containing TCDD and TCDF. Adverse effects on individuals may be important if the individuals affected are members of species that are endangered or threatened. In Maryland, the loggerhead shrike ingests a daily dose that is almost three times the NOAEL for nonmigratory birds. Furthermore, the eggs of this species have a TCDD concentration that is almost four times the TCDD "lowest observable adverse effect level" (or LOAEL) for eggs. The loggerhead shrike is considered a threatened species in that state.

This assessment does not attempt to quantify the effects of TCDD and TCDF on populations or ecosystems. However, the results of assessment show that at certain land application sites, the reproductive capability of individuals of certain species may be affected. Effects on the reproductive capability of a sufficient number of individual members of a species may lead to overall population effects for that species in that area.

In summary, this analysis finds that typical risks to human populations exposed to the TCDD and TCDF from pulp and paper mill sludge are generally low. Risks to "most exposed individuals", however, could be significant, depending on site-specific circumstances and individual human behavior. It also finds significant potential risks to wildlife associated with the land application of sludge, both to the health of individual specimens and to their reproductive capability. As discussed in Chapter 4, the "best estimates" of human and wildlife exposure and risk provided in this report should not be interpreted as precise quantification of exposure and risks, but rather as general indicators of the magnitude of those risks; separate calculations

Table 5.M. Summary of Risks to Birds ("Best Estimate")

Species	Lowest Value for Dose as a Percent of NOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of NOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	0	0	PA	309	169	OH
American Robin	1	0	PA, MS (TCDF)	413	114	GA
Great Crested Flycatcher	0	0	PA, MS (TCDF)	328	91	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	520	285	OH
Eastern Meadowlark	0	0	PA, MS (TCDF)	160	88	OH
Tree Swallow	2	1	ME	334	92	GA
Pine Warbler	3	1	ME	476	132	GA
Woodcock	15	8	ME	2761	764	GA
Woodthrush	1	1	ME	194	54	GA

Table 5.N. Summary of Risks to Bird Eggs ("Best Estimate")

Species	Lowest Value for Concentration as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Concentration as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Eastern Bluebird	1	0	PA	675	55	OH
American Robin	1	0	PA, MS (TCDF)	1059	44	GA
Great Crested Flycatcher	1	0	PA, MS (TCDF)	624	26	GA
Loggerhead Shrike	1	0	PA, MS (TCDF)	720	49	OH
Eastern Meadowlark	1	0	PA, MS (TCDF)	382	31	OH
Tree Swallow	5	0	ME	818	34	GA
Pine Warbler	4	0	ME	679	28	GA
Woodcock	34	3	ME	6237	288	GA
Woodthrush	2	0	ME	405	17	GA

Table 5.0. Summary of Risks to Mammals ("Best Estimate")

Species	Lowest Value for Dose as a Percent of LOAEL		State Where Lowest Value Occurs	Highest Value for Dose as a Percent of LOAEL		State Where Highest Value Occurs
	TCDD	TCDF		TCDD	TCDF	
Nine-banded Armadillo (1)	31	0	MS	31	0	MS
Grey Bat	2	0	PA, MS (TCDF)	1810	501	GA
Eastern Mole	2	0	PA, MS (TCDF)	1540	426	GA
River Otter	0	0	(2)	0	0	(2)
Virginia Opossum	0	0	PA, MS (TCDF)	288	80	GA
Least Shrew	6	0	PA, MS (TCDF)	4480	1240	GA
Striped Skunk	0	0	PA, MS (TCDF)	192	53	GA

(1) Armadillo only occurs in Mississippi

(2) River otter dose less than 0.5% in all states

performed with plausible "low risk" and "high risk" parameter values suggest that the "best estimate" results presented in this report could over- or under-estimate risks by several orders of magnitude.

References

Wisconsin Department of Health and Social Services (1989). Human Exposure Assessment for Dioxin and Furan Contaminated Papermill Sludge Applied to Soils. Division of Health, Final Draft, January.

6.0. Estimates of Exposure and Risks to Humans Based on Generic Scenarios

The site-specific risk assessment presented in the previous chapters reflects the risks from the current disposal and use of sludges contaminated with TCDD and TCDF, based on sludge concentration values reported in the 104-Mill Study database (U.S. EPA, 1989a). However, in the future, mills may choose to shift disposal or use practices. Such shifts may affect risk. Therefore, it is useful to accompany an evaluation of risks from the current pattern of sludge disposal and use with a evaluation of risks from generic, representative sites. This chapter describes a generic assessment of the risks from the disposal and use of pulp and paper sludge.

The construction of typical disposal and use scenarios is guided by knowledge of the characteristics of current actual disposal and use sites, but generalizes these practices. Further, the generic analysis assumes a constant level of sludge contamination across all disposal methods. Therefore, the analysis serves to point out the pathways and disposal methods that are intrinsically more risky, and that need to be more closely evaluated.

The methods used to assess risk are, for the most part, the same as the methods used in the site-specific assessment; however, several of the values used to represent the generic scenario in the exposure models differ from those used in the site-specific assessment. The following sections present the input parameters used to assess risk from each exposure pathway for each of the disposal and use methods, and describe input values that have been changed from the site-specific assessment.

Two changes are of particular note: (1) the change in the sludge concentrations assumed, and (2) the change in the way the TCDD slope factor was used. For the analysis of risks from each disposal method, the site-specific assessment used the TCDD and TCDF sludge concentrations reported by mills currently using that disposal method. Since the plants may shift sludge disposal practices over time, this approach is not appropriate for the generic assessment. The generic assessment uses values which are representative of TCDD and TCDF concentrations in sludge from all plants, regardless of their current disposal practices. The distribution of the concentrations of TCDD and TCDF over all of the plants appearing in the 104-Mill Study is shown in Table 6.0.A. For estimating typical exposure, the generic assessment assumes that sludge going to each disposal method contains TCDD and TCDF at a concentration equal to the mean concentration of sludge averaged over all plants. For the generic assessment of MEI risk, the 90th percentile concentrations of TCDD and TCDF are used.

Table 6.0.A. Distribution of TCDD and TCDF Sludge Concentrations for All Plants in 104-Mill Study

Distribution descriptor	TCDD concentration	TCDF concentration
N	79	79
M	27	27
Mean	162.9	885.4
Std Dev.	464.7	2303
Percentiles:		
100%	3800	17100
99%	3800	17100
95%	680	2940
90%	293	1760
75%	119	799
50%	51	158
25%	12	34
10%	3	6
5%	1.9	2.4
1%	0	0
0%	0	0

Notes:
N = number of plants reporting sludge concentrations
M = number of plants missing sludge concentration values
100th percentile = maximum value
0th percentile = minimum value

The generic assessment uses the slope factor for TCDD in a different manner than the site-specific assessment. To be consistent with other generic assessments conducted by the Agency, the slope factor derived by EPA's Carcinogen Assessment Group is used in the generic assessment.[1]

6.1 Exposure and Risks from the Disposal of Pulp and Paper Sludge in Landfills

Landfilling of sludge from the pulp and paper industry is defined as the burial of sludge on land, sometimes accompanied by the regular application of soil cover. As in the site-specific analysis described in Section 2.1, this analysis estimates human exposure to TCDD and TCDF through four exposure pathways associated with sludge landfills:

- Contaminants volatilize from the landfill and are transported by wind to neighboring areas. Humans inhale contaminated air and are exposed.
- Storm runoff carries contaminant-laden particles of soil from the surface of the landfill to nearby surface water bodies. Contaminants are then released from stream or lake sediments into surface water, which is withdrawn for drinking water supplies. Humans ingest the contaminated water and are exposed.
- Storm runoff caries TCDD and TCDF to surface water bodies, as described above. Fish accumulate TCDD and TCDF from the water or sediment. Humans ingest fish and are exposed.
- Rain water or sludge moisture carry dissolved contaminants from the bottom of the landfill to an aquifer underneath a landfill. Dissolved contaminants are then transported by the aquifer to nearby drinking water wells. Humans ingest contaminated water withdrawn from the wells and are exposed.

As explained in Section 2.1, the site-specific analysis used generic scenarios to estimate volatile emissions of TCDD and TCDF from a "typical" or "worst case" landfill to predict groundwater contamination beneath those facilities, and to predict the extent to which surface runoff might result in contamination of nearby surface water. Site-specific calculations were performed, however, to predict the transport of emitted contaminants by wind, and to determine the number of persons likely to be exposed through the air or groundwater pathways. The generic assessment reported in this section differs from the site-specific analysis in that it uses generic values for sludge concentrations and for estimating the sizes of populations exposed to contaminated groundwater. Input values used across all exposure pathways are presented in Table 6.1.A.

---

[1] The only exception is the dermal contact pathway. Exposure through this pathway is significantly different than the route by which the potency estimate was derived; therefore, an adjustment for bioavailability through dermal absorption is required.

Table 6.1.A. Assumptions and Parameter Values for Generic Assessment - Landfills: All Exposure Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Area of landfill (cm^2)	1.2×10^9	2.4×10^9	30 acres is thought to be typical. 60 acres is highest reported value.	U.S. EPA (1985). 104-Mill study.
Quantity of sludge received (DMT/yr)	19,500	76,700	Average and highest values reported.	104-Mill study
Landfill dimensions (m x m)	350 x 350	500 x 500	Assumes square site for 30 and 60 acre landfills.	
Facility lifetime (yrs)	14	14		U.S. EPA (1985)
Depth of landfill (m)	6	6	One landfill reported depth of 20 feet.	104-Mill study.
Site locations	Location of town containing each landfill.			104-Mill study
Depth of cover (cm)	0	0	Assumes that no soil cover is applied to landfills.	U.S. EPA (1988).
Fraction organic carbon in sludge	25%	25%	Median nitrogen content in combined sludges is 0.85%. Typical organic carbon-to-nitrogen ratios range from 17:1 to 45:1	NCASI (1984).

Table 6.1.A. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: All Exposure Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Fraction organic carbon in landfill	20%	20%	Appropriate for sludge.	
Soil porosity	0.25	0.25	Typical values.	
Soil disconnectiveness index	3.7	3.7	Typical values.	
Soil intrinsic permeability (cm^2)	1×10^{-8}	1×10^{-8}	Within range of permeabilities reported for "silty sand" and "clean sand".	Freeze and Cherry (1979).
True density of sludge/soil	2.65	2.65	Density of quartz.	
Bulk density of soil (kg/m^3)	1,400	1,400	Typical value for sand.	Yeh (1981).
TCDD concentration in sludge (ng/kg)	163	293	Average and 90th percentile concentrations.	104-Mill study.
TCDF concentration in sludge (ng/kg)	885	1,760	Average and 90th percentile concentrations.	104-Mill study.

Table 6.1.A. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: All Exposure Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320		Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987a).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).

Table 6.1.A. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: All Exposure Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS.
TCDF photolysis half life of vapor (min)	4,320	4,320	Assumed same as TCDD.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306		
TCDF Koc (cm^3/g)	3.5×10^4	3.5×10^4		Both values from CHEMEST procedure in GEMS.
TCDF Henry's Law Constant ($atm\ m^3/mol$)	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

6.1.1 Estimates of Exposure and Risks from Inhalation of Vapors

Methodology

Estimating human exposure and risk through the volatilization pathway involves three steps. First, the extent to which TCDD and TCDF are emitted from each landfill site is estimated. Second, the extent to which air concentrations of these contaminants will be reduced through wind transport and atmospheric decay processes is estimated. Finally, resulting air concentrations are mapped onto nearby populations in order to estimate the extent of human exposure and total human health risks. Methods used for each of these steps were described in Section 2.1.1. For the site-specific analysis, two different approaches were compared for estimating emissions from landfills. "Best estimates" were derived from results obtained from the SESOIL model; "high risk" estimates were derived with simpler set of equations. The generic risks assessment differs in that it uses the simpler approach (equations from Hwang and Falco, 1986, as described in Chapter 2.1) for both MEI and typical exposure and risk calculations. In addition, the generic risk assessment departs from "best estimate" calculations in Chapter 2.1 by assuming that soil cover is not applied to the landfills, and by using different values for assumed concentrations of TCDD and TCDF in the sludge.

Data Sources and Model Inputs

The values used for each input for typical and MEI exposure estimates are summarized in Table 6.1.B. A description of these parameters, and a discussion of the basis for particular values used, is presented in Section 2.1.1 . Differences between the site-specific and the generic analyses' assumptions for sludge concentration assumptions were discussed in Section 6.0. Except for the depth of soil cover (which is assumed to be 0 cm for the generic assessment) no other parameters differ between the two analyses.

6.1.2. Estimates of Exposure and Risks from Ingestion of Drinking Water from Groundwater Sources

Methodology

Estimating potential human exposure and risk from the contamination of groundwater near a landfill requires three steps: consideration of the transport of contaminants through the unsaturated zone beneath a facility, consideration of the transport of contaminants through an aquifer to a nearby drinking water well, and estimation of the number of humans who might be exposed to contaminated well water. As in the analysis reported in Section 2.1.2, the generic analysis uses the SESOIL model,

Table 6.1.B. Assumptions and Parameter Values for Generic Assessment - Landfills: Volatilization Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Model used to estimate emissions	Hwang and Falco (1986)	Hwang and Falco (1986)		
Model used to estimate wind transport and human exposure	ISCLT (area source)	ISCLT (area source)	Location - specific modeling for each site.	Bowers et al. (1980); GEMS; U.S. EPA (1984.
Meterological data for ISCLT	STAR data accessed through GEMS (site specific).			GEMS; U.S. EPA (1984).
Emission period (yrs.)	70	70	Corresponds to length of exposure for cancer risk calculations.	
Landfill status at beginning of emission period	Full	Full	Will tend to overestimate emissions.	
Population densities and locations	Census data accessed through GEMS (site specific).			GEMS.

and a "typical" landfill scenario, to examine the likely migration of sludge contaminants from the landfill to the aquifer, and the AT123D model to estimate the extent to which contaminant concentrations are expected to decrease during transport within the aquifer to a nearby well. Corresponding estimates for the MEI scenario are based on identical inputs, but with a larger area (60 acres) for the landfill. The generic and site-specific analyses then estimate the extent of human exposure by estimating the number of persons likely to draw drinking water from each of three ranges of distances downgradient of a landfill site, and assuming that each of the populations living within each of these three distances is exposed to the predicted level of groundwater contamination.

Data Sources and Model Inputs

The values used for each input for typical and MEI exposure estimates are summarized in Table 6.1.C. For a description of these input parameters and an explanation of the values selected, the reader is referred to Chapter 2.1. Differences between the site-specific and the generic analyses with respect to sludge concentrations were discussed in Section 6.0. Additional differences between the two analyses are described below.

Data Sources and Model Inputs for Estimating the Size of Exposed Populations

For the site-specific analysis, data from the National Well-Water Association, FRDSPWS, and Statistical Abstracts were analyzed to determine the average density of persons drinking groundwater per unit of land area within each of the counties reported to contain a landfill site. These densities were then applied to the estimated area of land under which groundwater was contaminated to estimate the number of persons in each county likely to be exposed to each level of groundwater contamination. That analysis estimated that approximately 0.33 persons drink groundwater per hectare, in counties containing landfills for pulp and paper sludge. For the generic analysis, it is assumed that the density of persons drinking groundwater is the same for all landfills, and that this density corresponds to the average for the United States as a whole, or approximately 68 persons per square mile (0.26 per hectare). This value is used to estimate the sizes of exposed populations listed in Table 6.1.C .

Table 6.1.C. Assumptions and Parameter Values for Generic Assessment - Landfill: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Model used to estimate loading to aquifer	SESOIL	SESOIL		Bonazountas and Wagner (1984).
Result used for exposure estimates	Steady state	Steady state		
Model used for transport through saturated zone	AT123D	AT123D		Yeh (1984); U.S. EPA (1988).
Result used for exposure estimates	Steady state	Steady state		
Distance to aquifer (m)	3	3	Assumes 6 meter depth from landfill surface to water table. Sludge layer extends to 3m below landfill surface, but contaminants and organic carbon are distributed throughout 6m landfill depth.	DRASTIC database.
Aquifer medium	Sand and gravel	Sand and gravel	Most common aquifer medium reported in DRASTIC data base for counties containing landfills.	
Depth of aquifer (m)	100	100		
Width of aquifer (m)	Infinite	Infinite		

Table 6.1.C. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Distance to model wells (m)	200 1200 3000	200	Midpoints of ranges listed below.	
Distances represented (m)	0-400 400-2,000 2,000-4,000	200		
Exposed populations			Assumes density of 68 persons per square mile.	
0-400 m	195	--		
400-2000 m	4,670			
2000-4000 m	14,600			
Decay	0	0	No decay rate available for TCDD or TCDF in groundwater.	
Effective porosity of aquifer medium	0.25	0.25	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	10	10	Appropriate for productive sand and gravel aquifer.	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	Typical value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	Within range of "typical" values reported for sand or silt. Values equal approximately 1/10 distance to nearest receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 6.1.C. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Transverse dispersivity (m)	7	7	Within range of "typical" values reported for sand or silt. Equals 1/3 of longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Vertical dispersivity (m)	1	1	Within range of "typical" values reported for sand.	Yeh (1980).
TCDD K_D in aquifer	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$, and organic carbon = 0.1%.

6.1.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources

Methodology

The methodology used for the generic assessment is identical to that used for the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.1.3. In general, the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, is used to estimate the fraction of a lake's or stream's sediment that originates from the landfill. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the landfill surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases. Contaminant concentrations in water are combined with data on human rates of water ingestion, the size of the population exposed, and slope factors to yield exposure and risk estimates.

Data Sources and Model Inputs

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 6.1.D for both typical individuals and the MEI. Differences between the site-specific and the generic sludge concentration assumptions were discussed in Section 6.0. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the organic carbon:water partition coefficient, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the sediment:water partition coefficient. In the site-specific assessment the MEI "best estimate" assumes a one percent organic carbon content in the sediment. The generic MEI assessment assumes a 0.1 percent organic carbon content. The effect of this change will be a decrease in the sediment contamination level and an increase in the water contamination level.

Data Sources and Model Inputs for Estimating the Size of the Exposed Population

In the site-specific analysis, the size of the exposed population was estimated by multiplying the watershed area of the contaminated stream by the population density of the regions in which the

Table 6.1.D. Assumptions and Parameter Values for Generic Assessment - Landfills: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
SMA Soil Cover	None	None		
SMA Vegetative Cover	90%	None		Typical: U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
"C" ratio	1.1:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	USDA (1978) "Predicting Rainfall Erosion Losses," December
"P" ratio	1:1	1:1	Assumes no support practices.	
Distance from site to surface water (meters)	152	30		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Drainage Area (ha)	1,295,000	4,047	Typical scenario assumes the sites drain into a major waterway. The MEI scenario assumes the sites drain into a relatively small stream.	
Fraction Organic Carbon in Sediment	0.01	0.001		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)

Table 6.1.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100		
Fish to sediment ratio				
- Dioxin	1	10		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
- Furan	1	10		
Fish consumption (grams/day)	6.5	140	Includes fresh water and estuarine fish and shellfish.	Typical: U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft) MEI: U.S. EPA Office of Water
Percent of fish consumed by the exposed population that is contaminated	100	100		

Table 6.1.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Landfills: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Concentr in filet vs. conc tion in whole fi	0.5	0.5		U.S. EPA memo, "Bio-concentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Populati ensity (people/ e mile)	68	N.A.	U.S. average population density.	U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent pulation served b face water	49	N.A.	U.S. national average.	U.S. Geological Survey (1985)

Notes: = Not applicable.

sludge management areas (SMAs) were located. In the generic analysis, a national population density (68 people per square mile) replaces the regional population density.

6.1.4 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Methodology

The methodology used to calculate risk from ingestion of contaminated fish in the generic assessment is identical to that used in the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.1.3. The calculation follows the methodology discussed in Section 6.1.3 through the estimation of sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from landfill sites. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 6.1.3, and uses fish to sediment bioconcentration factors and estimates of human consumption of fish to calculate contaminant doses to humans. Finally, estimates of the size of the exposed population are combined with estimates of individual dose and health risk to derive total health risks to the entire exposed population.

Data Sources and Model Inputs

Data sources and model inputs for estimating fish contaminant concentrations can be found in Table 6.1.D for both typical individuals and the MEI. Differences between the site-specific and generic sludge concentration assumptions were discussed in Section 6.0. The differences in the Kd, the sediment:water partition coefficient and in the size of the population exposed to the contaminant presented in Section 6.1.3 also apply to the assessment of risks from ingestion of contaminated fish. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Data Source and Model Inputs for Estimating the Fish to Sediment Bioconcentration Factor

Both the site-specific analysis and the generic analysis calculate bioaccumulation in fish as a function of a fish-to-sediment bioconcentration factor. In the site-specific analysis of typical and MEI risk, the bioconcentration factors used for TCDD and TCDF were 0.0967 and 0.1538, respectively (U.S. EPA, 1989b). Based on a review of fish to sediment bioconcentration factors by U.S. EPA (1988a) a fish to sediment ratio of 1:1 is used in the generic analysis of typical risk. This value is used for both TCDD and TCDF. The fish bioconcentration factor used in the generic MEI assessment also differs from the value used in the site-specific MEI assessment. A fish to sediment ratio of 10:1 is used in the generic MEI assessment for both TCDD and TCDF (U.S. EPA, 1988a).

Data Sources and Model Inputs for the Rate of Human Consumption of Fish

Although the generic and site-specific assessments use the same rate of human consumption of fish to calculate typical exposure, the consumption rates differ between the two analyses for the MEI calculations. A consumption rate of 100 grams per day was used in the site-specific assessment (U.S. EPA, 1988b). This consumption rate reflects the upper 90th percentile consumption rate of freshwater fish for sport fishers in the Great Lakes area. In the generic assessment, the MEI is assumed to be a subsistence fisher consuming freshwater at the rate of 140 grams per day (U.S. EPA Office of Water).

6.1.5 Summary of Results

The estimates of typical and MEI exposure and health risks from the landfilling of paper mill sludge containing TCDD and TCDF are summarized in Tables 6.1.E and 6.1.F. The tables show that the greatest risk to the MEI is through consumption of contaminated fish. This pathway results in risks of 5×10^{-2}. Ingestion of contaminated surface water results in an MEI risk of 7×10^{-4}. The ground water and volatilization pathways result in risks to the MEI that are several orders of magnitude lower than the risks resulting from surface water runoff.

The greatest risk to a typical individual is estimated to be 8×10^{-8} and results from the consumption of contaminated fish. The highest risk to a typical individual is therefore about six orders of magnitude lower than the greatest risk to the MEI. The pathways which contribute the highest number of cancer cases per year to the entire U.S. population are the same as those contributing the highest MEI risk: consumption of contaminated fish and ingestion of contaminated surface water.

The risks from all landfill exposure pathways except fish consumption are dominated by TCDF. This is a result of TCDF's higher solubility and volatility as compared with TCDD.

6.2 Exposure and Risk from Disposal of Pulp and Paper Sludge in Surface Impoundments

Surface impoundments are defined as facilities in which sludge from pulp and paper mills is stored or disposed on land without a cover layer of soil. It is assumed that sludge contained in

Table 6.1.E. Human Exposure Estimates from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Expos athway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhal exposure from volatilization from fills in which sludge is disposed:	3×10^{-12}	(4.03)	8×10^{-15}	(4.03)
Inge exposure from drinking groundwater conta ted by leachate from landfills in w udge is disposed:	8×10^{-15}	(2)	7×10^{-16}	(8)
Inge exposure from drinking surface wate taminated by surface runoff from fills in which sludge is disposed:	5×10^{-9}	(0.6)	3×10^{-13}	(0.64)
Inge exposure from fish caught in surf ater contaminated by runoff from fills in which sludge is disposed:	3×10^{-7}	(63)	5×10^{-13}	(65)

Note

[a] Eq estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Ca ed as: $100 \times \dfrac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 6.1.F. Human Health Risk Estimates from Landfill Disposal of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exp pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inh on exposure from volatilization fro dfills in which sludge is disposed: (P TCDD)[c]	4×10^{-7} (4.03)	1×10^{-9} (4.44)	12,800,000	2×10^{-4} (4.44)
Ing exposure from drinking groundwater con ated by leachate from landfills in sludge is disposed: (P TCDD)[c]	1×10^{-9} (2)	1×10^{-10} (8)	19,000	3×10^{-8} (8)
Ing on exposure from drinking surface wa ntaminated by surface runoff fr dfills in which sludge is disposed: (P TCDD)[c]	7×10^{-4} (0.6)	5×10^{-8} (0.6)	6,980,000	5×10^{-3} (0.6)
Ing on exposure from fish caught in su water contaminated by runoff fr ndfills in which sludge is disposed: (P TCDD)[c]	5×10^{-2} (63)	8×10^{-8} (65)	14,200,000	2×10^{-2} (65)

[a] ated as: [Estimated Exposure] x 1.5 x 10^5

[b] ated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] ated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

such facilities contains more moisture than the sludge deposited in landfills, at least in the active phase of the surface impoundment. As in the analysis reported in Section 2.1.3, this generic analysis estimates human exposure to TCDD and TCDF through four exposure pathways associated with surface impoundments:

- Volatilized TCDD and TCDF are emitted from the impoundment surface. These are transported downwind to nearby areas. Humans inhale the contaminated ambient air, and are exposed.
- Contaminants from sludge placed in the impoundment are dissolved in water seeping through the bottom of the facility. Contaminated water enters an aquifer beneath the impoundment, and flows down-gradient to drinking water wells. Humans withdraw drinking water from the contaminated aquifer and are exposed.
- Surface runoff carries particles of sludge from the surface of the impoundment to a nearby lake or stream. TCDD and TCDF adsorbed to these particles enter the surface water body, and are released to surface water. Humans withdraw surface water for drinking and are exposed.
- Surface runoff carries particles of sludge from the surface of the impoundment to a nearby lake or stream, where the particles are suspended or settle to bottom sediment. Fish absorb and bioconcentrate TCDD and TCDF from the sludge particles. Humans ingest the fish, and are exposed.

For the site-specific analysis described in Chapter 2.3, generic scenarios were constructed to represent "typical" and "worst case" surface impoundments to estimate exposure for a typical and most exposed individual, respectively. These generic scenarios were used to predict the extent to which groundwater, surface water, or ambient air might be contaminated near such a facility. Site-specific parameters were then used to determine the extent to which humans might be exposed to contaminants transported from each actual facility. The generic analysis uses the same scenarios as the site-specific analysis; however, there are some differences in the input values used, as outlined below for each exposure pathway. Input values used across all pathways are presented in Table 6.2.A.

6.2.1. Estimates of Exposure and Risk from Inhalation of Vapors

Methodology

Risks from the inhalation of TCDD and TCDF emitted from surface impoundments are estimated with three steps: 1) estimation of the rate at which these two contaminants volatilize from the impoundment, 2) estimation of the extent to which concentrations of emitted contaminant in ambient are decreased during wind transport to surrounding areas, and 3) estimation of the sizes of populations exposed to each level of contamination. The site-specific analysis discussed in Section 2.3.1 used a generic scenario (and a two-phase resistance model) to predict emissions from a surface

Table 6.2.A. Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: All Exposure Pathways

ter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
of dments te	3	3		U.S. EPA (1985).
f each dment s)	25	50		U.S. EPA (1985). 104-Mill study.
of dment	3	3		
ion organic in sludge wt)	25%	25%	Median nitrogen content in combined sludges is 0.85%. Typical organic carbon: nitrogen ratios range from 17:1 to 45:1	NCASI (1984).
ge sludge tration pt)	163	293	Average and 90th percentile concentrations.	104-Mill study.
ge sludge tration (ppt)	885	1,760	Average and 90th percentile concentrations.	104-Mill study.

Table 6.2.A. (cont.) Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: All Exposure Pathways

ut meter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
rage quantity sludge eived T/yr)	28,653	91,250	Average and highest reported quantities.	104-Mill study.
D diffusivity air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
D diffusivity water ^{2}/sec)	5.5 x 10^{-6}	5.5 x 10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
solubility ater g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
photolysis life of vapor	4,320	4,320		Mill (1985); Atkinson (1987).
molecular ht	322	322		
Koc g)	1 x 10^7	1 x 10^7		Jackson (1985) as reported in U.S. EPA (1987a).
Henry's Constant ^{3}/mol	1.6 x 10^{-5}	1.6 x 10^{-5}		Podol (1986).

Table 6.2.A. (cont.) Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: All Exposure Pathways

ut meter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
F fusivity in (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
F fusivity in er ^{2}/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
F solubility water /g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS.
DF photolysis f life of or (min)	4,320	4,320	Assumed same as TCDD.	Mill (1985); Atkinson (1987).
DF molecular ght	306	306		
F Koc	3.5×10^4	3.5×10^4		From CHEMEST procedure in GEMS using Kenaba method.
DF Henry's Constant m^3/mol	8.6×10^{-5}	8.6×10^{-5}		CHEMEST procedure in GEMS.

impoundment, but used site-specific data, together with the ISCLT model, to predict the wind transport of contaminants in ambient air, and the subsequent exposure of humans living in surrounding areas. The generic analysis uses identical methods to perform these calculations.

Data Sources and Model Inputs

Values used for each input parameter for typical and MEI exposure estimates are presented in Table 6.2.B. A description of these parameters, is provided by Section 2.3.1, along with justification for the values used for the site-specific analysis. Data for estimating emissions for the generic analysis differ from those used for the analysis discussed in Section 2.3.1 only in the concentrations of TCDD, as discussed in Section 6.0. All other inputs are the same as those discussed in Chapter 2.3.

6.2.2. Estimates of Exposure and Risks from Ingestion of Drinking Water from Groundwater Sources

Methodology

Estimating potential groundwater contamination and human exposure from a surface impoundment requires three steps: (1) estimating the rate at which contaminants seep from the bottom of the impoundment and are transported through the unsaturated zone, (2) estimating the extent to which concentrations of contaminant within the aquifer are reduced prior to reaching a drinking water well, and (3) estimating the extent of likely human exposure at various distances from the site. Section 2.3.2 describes methods used for each of these steps for the site-specific analysis. For "best estimates" of the transport of contaminants to groundwater, that analysis assumed that the impoundment is no longer active when most of the migration of contaminants to groundwater takes place, and used the SESOIL model to calculate the rate of expected loadings of contaminant to the aquifer. The generic analysis follows an identical approach with the SESOIL model.

Data Sources and Model Inputs

Input parameter values for estimating exposure from typical and MEI scenarios for the generic analysis are provided in Table 6.2.C. Most of those values are identical to those used in Section 2.3.2. Exceptions are the sludge contamination levels (discussed in Section 6.0) and the size of the exposed population.

Table 6.2.B. Assumptions and Parameters Values for Generic Assessment - Surface Impoundments: Volatilization Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Model used to estimate emissions	Two-phase resistance	Two-phase resistance		U.S. EPA (1987); Springer et al. (1984); Hwang (1982).
Model used to estimate wind transport and human exposure	ISCLT	ISCLT		Bowers et al. (1980); GEMS; U.S. EPA (1984).
Temperature (°C)	25	25		
Average wind-speed (m/sec)	4.5	4.5	Single average windspeed used to estimate emissions. Site-specific windspeeds and direction used for ISCLT calculations.	4.45 m/s = 10 mph, average for 60 U.S. cities from (U.S. EPA, 1988b)

Table 6.2.C. Assumptions and Parameters Values for Generic Assessment - Surface Impoundments: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Model used for transport through unsaturated zone	SESOIL	SESOIL	Aassumes that long term average recharge to aquifer is not affected by water in impoundment.	U.S. EPA (1987b).
Result used for exposure estimates	Steady state	Steady state		
Model used for transport in aquifer	AT123D	AT123D		Yeh (1984); U.S. EPA (1989).
Result used for exposure estimates	Steady state	Steady state		
Vertical distance to aquifer (m)	3	3	Assumes 6 meter depth to water table.	DRASTIC database.
Aquifer recharge (cm/yr)	43	43	Estimate represents typical recharge rate for areas with surface impoundments. Assumes long-term recharge is not affected by water in impoundment.	

Table 6.2.C. (cont.) Assumptions and Parameters Values for Generic Assessment - Surface Impoundments: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Vadose zone medium	Sand & gravel, silt & clay	Sand & gravel, silt & clay	Most common medium in counties containing surface impoundments.	DRASTIC data base in GEMS.
Hydraulic conductivity of unsaturated zone (m/sec)	1×10^{-7}	1×10^{-7}	Selected value is between ranges typical for sand and for clay. Would result in complete drainage of inactive lagoon within three years.	Freeze and Cherry (1979).
Effective porosity of aquifer medium	0.25	0.25	Appropriate for sand and gravel.	Freeze and Cherry (1979); Yeh (1981).
Hydraulic conductivity (m/hr)	10	10	Appropriate for productive sand and gravel aquifer.	Freeze and Cherry (1979).
Hydraulic gradient	1%	1%	"Typical" value.	U.S. EPA (1988).
Longitudinal dispersivity (m)	20	20	Within range of "typical" values reported for sand. Equals approx. 1/10 distance to receptor well.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
Transverse dispersivity (m)	7	7	Within range of "typical" values reported for sand. Equals 1/3 longitudinal dispersivity.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).

Table 6.2.C. (cont.) Assumptions and Parameters Values for Generic Assessment - Surface Impoundments: Groundwater Pathway

Input parameter	Estimate for typical individual	Estimare for MEI	Notes/explanation	Reference
Vertical dispersivity (m)	1	1	Within range of "typical" values reported for sand.	Yeh (1980). Federal Register Vol. 51, No. 9, p. 1652 (1986).
TCDC K_D in aquifer	10,000	10,000	Does not affect steady state results.	Based on $K_{OC} = 1 \times 10^7$, and organic carbon = 0.1%.
TCDF K_D in aquifer	35	35	Does not affect steady state results.	Based on $K_{OC} = 3.5 \times 10^4$,. and organic carbon = 0.1%.
Distance to model wells (m)	200 1,200 3,000	200	Midpoints of ranges listed below.	
Distances represented (m)	0-400 400-2,000 2,000-4,000	200		
Exposed populations				
0-400 m	63	--	Assumes density of 68 persons per square mile.	Average for U.S.
400-2,000 m	1,500			
2,000-4,000 m	4,670			

Data Sources and Model Inputs for Predicting the Size of Exposed Populations

Section 2.3.2 describes methods for using site-specific data to estimate the number of persons likely to ingest well-water taken from areas within the contaminant plume down-gradient of a surface impoundment. Based on data from the National Well Water Association, FRDSPWS, and Statistical Abstracts, it was estimated that an average of 0.17 persons take drinking water from wells within each hectare of land in counties containing surface impoundments. The generic analysis follows a different approach, in which the density of persons potentially exposed is assumed to be constant throughout the United States. To calculate the size of the exposed populations, the size of the affected area down-gradient of each site (within 400, 2000, or 4000 meters) is simply multiplied by a single average population density (68 persons per square mile or 0.26 per hectare). The results are multiplied by the number of existing facilities reporting the use of surface impoundments (20) to estimate the sizes of exposed populations listed in Table 6.2.C . Resulting estimates of the size of the exposed populations are therefore higher than those used for the site-specific calculations described in Section 6.3.2.

6.2.3 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources

Methodology

The methodology used for the generic assessment is identical to that used for the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.3.3. In general, the methods use the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, to estimate the fraction of a lake's or stream's sediment that originates from the surface impoundment. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the surface impoundment surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases. Contaminant concentrations in water are combined with data on human rates of water ingestion, the size of the population exposed, and slope factors to yield exposure and risk estimates.

Data Sources and Model Inputs

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 6.2.D for both typical individuals and the MEI. Section 6.0 discussed the

Table 6.2.D. Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
SMA Soil Cover	None	None		
SMA Vegetative Cover	90%	None		Typical: U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
"C" ratio	1.1:1	10:1	All scenarios assume that the surrounding drainage area is pasture land.	USDA (1978) "Predicting Rainfall Erosion Losses," December
"P" ratio	1:1	1:1	Assumes no support practices.	
Distance from site to surface water (meters)	152	30		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Drainage Area (ha)	1,295,000	4,047	Typical scenario assumes the sites drain into a major waterway. The MEI scenario assumes the sites drain into a relatively small stream.	
Percent Organic Carbon in Soil	0.01	0.001		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA (1988) "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)

Table 6.2.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100		
Fish to sediment ratio				
- Dioxin	1	10		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
- Furan	1	10		
Fish consumption (grams/day)	6.5	140	Includes fresh water and estuarine fish and shellfish.	Typical: U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft) MEI: U.S. EPA Office of Water
Percent of fish consumed by the exposed population that is contaminated	100	100		

Table 6.2.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Surface Impoundments: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA memo, "Bioconcentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	68	N.A.	U.S. average population density.	U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	49	N.A.	U.S. national average.	U.S. Geological Survey (1985)

Notes: N.A. = Not applicable.

sludge concentrations assumed in the site-specific and generic scenarios. Additional differences in model inputs between the generic assessment and the site-specific assessment are discussed below.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the organic carbon:water partition coefficient, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the sediment:water partition coefficient. In the site-specific assessment the MEI "best estimate" assumes a one percent organic carbon content. The generic MEI assessment assumes a 0.1 percent organic carbon content. The effect of this change will be a decrease in the sediment contamination level and an increase in the water contamination level.

Data Sources and Model Inputs for Estimating the Size of the Exposed Population

In the site-specific analysis, the size of the exposed population was estimated by multiplying the watershed area of the contaminated stream by the population density of the regions in which the SMAs were located. In the generic analysis, a national population density (68 people per square mile) replaces the regional population density.

6.2.4 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Methodology

The methodology used for the generic assessment is identical to that used for the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.3.3. The calculations follow the methodology presented Section 6.2.3 through the estimation of sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from surface impoundments. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 6.2.3, and uses fish to sediment bioconcentration factors and estimates of human consumption of fish to calculate contaminant doses to humans. Finally, the size of the exposed population is combined with estimates of individual dose and health risk to derive total health risks to the entire exposed populations.

Data Sources and Model Inputs

Data sources and model inputs for estimating fish contaminant concentrations can be found in Table 6.2.D for both typical individuals and the MEI. Differences between the site-specific and generic assumptions regarding sludge concentration are discussed in Section 6.0. The differences in the sediment:water partition coefficient used and in the size of the population exposed presented in Section 6.2.3 also apply to the assessment of risks from the ingestion of contaminated fish. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Data Source and Model Inputs for Estimating the Fish to Sediment Bioconcentration Factor

Both the site-specific analysis and the generic analysis calculate bioaccumulation in fish as a function of a fish-to-sediment bioconcentration factor. In the site-specific analysis of typical and MEI risk, the bioconcentration factors used for TCDD and TCDF were 0.0967 and 0.1538, respectively (U.S. EPA, 1989b.) Based on a review of fish to sediment bioconcentration factors by U.S. EPA (1988a) a fish to sediment ratio of 1:1 is used in the generic analysis of typical risk. This value is used for both TCDD and TCDF. The fish bioconcentration factor used in the generic MEI assessment also differs from the value used in the site-specific MEI assessment. A fish-to-sediment ratio of 10:1 is used in the generic MEI assessment for both TCDD and TCDF (U.S. EPA, 1988a).

Data Sources and Model Inputs for the Rate of Human Consumption of Fish

Although the generic and site-specific assessments use the same rate of fish consumption to calculate typical exposure, the consumption rates differ for the MEI calculations. A consumption rate of 100 grams day was used in the site-specific assessment (U.S. EPA, 1988b). This consumption rate reflects the upper 90th percentile ingestion rate of freshwater fish for sport fishers in the Great Lakes area. In the generic assessment, the MEI is assumed to be a subsistence fisher consuming freshwater at the rate of 140 grams per day (U.S. EPA Office of Water).

6.2.5 Summary of Results

The estimates of typical and MEI exposure and health risks from the disposal of paper mill sludge in surface impoundments are summarized in Tables 6.2.E and 6.2.F. The tables indicate that the largest risk to the MEI is through consumption of contaminated fish. This pathway results in an MEI risk of 1×10^{-1}. Ingestion of contaminated surface water results in an MEI risk of 2×10^{-3}. The ground water and volatilization pathways result in risks to the MEI that are several orders of magnitude lower than the risks resulting from surface water runoff.

The highest typical individual risk is therefore about six orders of magnitude lower than the greatest risk to the MEI. The greatest risk to a typical individual is estimated to be 1×10^{-7}, and results from consumption of contaminated fish. The pathways which contribute the highest number

Table 6.2.E. Human Exposure Estimates from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF.

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed:	9×10^{-12}	(0.6)	3×10^{-13}	(0.7)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed:	2×10^{-13}	(0.4)	3×10^{-15}	(0.7)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed:	1×10^{-8}	(0.6)	4×10^{-13}	(0.7)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed:	7×10^{-7}	(63)	7×10^{-13}	(65)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 6.2.F. Human Health Risk Estimates from Surface Impoundment of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Inhalation exposure from volatilization from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	1×10^{-6} (0.6)	4×10^{-8} (0.7)	7,100,000	4×10^{-3} (0.7)
Ingestion exposure from drinking groundwater contaminated by leachate from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	3×10^{-8} (0.4)	5×10^{-10} (0.7)	6,000	4×10^{-8} (0.7)
Ingestion exposure from drinking surface water contaminated by surface runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	2×10^{-3} (0.6)	7×10^{-8} (0.7)	2,330,000	2×10^{-3} (0.7)
Ingestion exposure from fish caught in surface water contaminated by runoff from surface impoundments in which sludge is disposed: (Percent TCDD)[c]	1×10^{-1} (63)	1×10^{-7} (65)	4,760,000	7×10^{-3} (65)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

of annual cancer cases to the entire U.S. population are the same as those contributing the highest MEI risk: consumption of contaminated fish and ingestion of contaminated surface water.

The risks from all surface impoundment exposure pathways except fish consumption are dominated by TCDF. This is a result of TCDF's higher solubility and volatility as compared with TCDD.

6.3 Exposure and Risks from Land Application of Pulp and Paper Sludge

Land application of sludge, while an alternative disposal method, also fertilizes and conditions soil and allows the sludge to be used as fill. Sludge may be applied to agricultural sites, to mines and to forests. Exposure pathways of concern differ among the types of land receiving the sludge. For example, land application at agricultural sites may expose onsite residents (i.e., farmers) to TCDD and TCDF through pathways that are not relevant at mine/forest sites assuming that there are no permanent residents at the mine and forest sites. The following pathways of exposure are considered in this analysis:

Human risk estimates for forest application and mine reclamation consider two pathways:

- Contaminated soil erodes from the forest or mine site and contaminates surface water and stream sediment. The surface water serves as a drinking supply.
- Contaminated soil erodes from the forest or mine site and contaminates surface water and sediment. TCDD and TCDF is incorporated into fish tissue and fish are consumed by humans.

Human risk estimates from agricultural application consider the two pathways above and add the following pathways:

- Small amounts of contaminant are taken up into the tissues of crops. These crops are then either consumed by members of the farm household or distributed in the general market; or these crops are fed to animals which bioconcentrate the contaminant. The meat or dairy products produced from these animals are consumed by the farm household or distributed in the general market.

- Children and adults in the farming household come into direct dermal contact with the sludge-amended soil in both outdoor and indoor settings. TCDD and TCDF from the sludge is absorbed through the skin. Children ingest small amounts of the sludge/soil mixture through normal mouthing behavior. Adults also inadvertently ingest small quantities of sludge/soil.

- TCDD and TCDF applied to the farmland volatilizes from the sludge into the air. Residents of the farm inhale the volatilized TCDD and TCDF.

- Particles of the sludge/soil mixture become suspended in the air during application. Residents of the farm inhale the contaminated particles.

The models used to estimate risk for each of these pathways are identical to the models used in the site-specific assessment and are therefore not repeated. Model parameter values used in the generic assessment that differ from the site-specific assessment are described for each pathway. Data inputs not specifically discussed are consistent with the site-specific assessment. For a complete discussion of the land application methodology and of the data sources used to select input values, the reader is referred to Section 2.4. The parameters used to estimate soil concentrations in the generic assessment are presented in Table 6.3.A, and are discussed below. Table 6.3.B presents data regarding physical/chemical characteristics of TCDD and TCDF needed in the analysis of several exposure pathways. Results from the analysis of generic land application practices are summarized in the Section 6.3.8.

Differences in Calculation of Soil Concentrations

Four input parameters are needed to determine the concentration of contaminants in soil: (1) the concentration of the contaminants in the sludge, (2) the sludge application rate, (3) the incorporation depth of the sludge, and (4) the time period over which sludge is applied. Differences between the assumed sludge concentrations used in the site-specific assessment and the generic assessment were discussed in Section 6.0. Additional differences between the two assessments' assumptions in calculating soil concentrations are discussed below.

In the site-specific assessment, application rates particular to each state were used to calculate soil concentrations. In the generic assessment only two application rates are used - one for the agricultural application scenario and one for the mine and forest application scenario. To estimate reasonable values for these generic application rates, the rates of agricultural application obtained

Table 6.3.A. Parameters and Model Inputs Used for Generic Exposure Assessment to Model Land Application Practices

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Application rate (DMT/Ha)				
Forest/Mine	776	776	Average of individual states	State Environmental Officials
Agriculture	38	38		
Years land receives sludge				
Forest/Mine	1	1	Estimates based on information from	
Agriculture	20	70	individual states	
Incorporation depth (cm)				
Forest/Mine	0	0	Estimates based on information from	
Agriculture	15	15	individual states	
TCDD Concentration in Soil (ppt)				
Forest/Mine	163	293	See Appendix A	
Agriculture	35	107		
TCDF Concentration in Soil (ppt)				
Forest/Mine	885	1,760	See Appendix A	
Agriculture	188	645		

Table 6.3.B. Parameters and Model Inputs Used to Model Land Application for Generic Assessment

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986), at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320		Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 6.3.B. (cont.) Parameters and Model Inputs Used to Model Land Application for Generic Assessment

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	4,320	Assumed same as TCDD.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306		
TCDF Koc	3.5×10^4	3.5×10^4		Value from ChemEst procedure in GEMS, using Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

from states were averaged and the rates of forest and mine application obtained from states were averaged. Application rates that were estimated based on practices in other states were not included in the averages.

In both the site-specific and the generic analysis, it is assumed that sludge that is applied agriculturally is incorporated to a depth of fifteen centimeters. Sludge applied to reclaim mines is assumed to be top-dressed in both analyses. For silvicultural applications of sludge, the site-specific assessment assumed that sludge was incorporated at a depth of two and one-half centimeters. This reflects the accumulation of duff and the incorporation effects of activity on the forest floor. In the generic analysis, however, silvicultural application is analyzed as a unit with mine reclamation, and conservatively assumed not to be incorporated with the soil.

In both assessments, calculations of soil concentrations for mine reclamation and silvicultural applications assume a one-time application. In the site-specific assessment, agricultural land in Mississippi was assumed to receive sludge for 70 years; in Pennsylvania sludge was assumed to be applied for 20 years. These time periods were based on information from officials in each state. In the generic assessment, agricultural applications of sludge are assumed to continue for 70 years in the MEI analysis and for 20 years in the typical analysis.

6.3.1 Estimates of Exposure and Risks from Dermal Contact with Skin

Methodology

Risks from dermal exposure are calculated as a function of the amount of soil in contact with the skin, the length of time the soil remains on the skin, and the dermal absorption rate. The methods used to estimate risks from dermal contact with sludge-contaminated soil are described in Section 2.4.1.

Data Sources and Model Inputs

The values used for each model input for typical and MEI exposure estimates are summarized in Table 6.3.C. A description of these input parameters, and a discussion of the basis for selecting input parameter values, are found in Section 2.4.1. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. There are no other differences between the two analyses for this exposure pathway. There are no other differences between the two analyses for this exposure pathway. It is important to note that in other pathways considered in the generic assessment, the bioavailability of TCDD is assumed to be 100%. However, dermal absorption of

Table 6.3.C. Assumptions and Parameter Values for Generic Assessment - Land Application: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	0.5	1.5	Roels (1980) used in Schaum (1984) to develop MEI value; Lepow (1975) cited by Schaum for typical estimate value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	0.5	1.5	Roels (1980) used in Schaum (1980) MEI value; Lepow (1975) cited by Schaum for typical estimate value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	3.5	3.5	Typical and MEI estimate from Hawley (1985) based on adults doing yard work.	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.056	0.06	MEI value is from Solomon and Hartord (1976) as cited by Hawley. Typical estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.056	0.06	MEI value is from Solomon and Hartord (1976) as cited by Hawley. Typical estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space, indoor, adult attic	0.056 1.8 (110 mg/hr)	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985

Table 6.3.C. (con't.) Assumptions and Parameter Values for Generic Assessment - Land Application: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Ratio of contaminant concentration indoors to soil concentration outdoors	0.80	0.85		Hawley, 1985
Time spent outdoors, child (hr)	1565	2190	Typical estimate: assumes 5 days/wk, 6 months/yr, 12 hrs/day (12 hrs before soil is washed off); MEI: assumes 7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	1824	2190	Typical: child outdoors from May to September every day (150 days), 12 hrs of soil contact before washing; MEI estimate: child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	1565	1565	Both typical and MEI estimates: assume 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Typical: Hawley, 1985; MEI: Adopted from Keenan, 1989
Time spent indoors, child (hr)	4380	6570	Typical: 12 hrs/day of indoor dust contact all year; MEI: assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989
Time spent indoors, older child (hr)	1460	4380	Typical: assumes 4 hrs/day of indoor dust contact all year; MEI: assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985

Table 6.3.C. (con't.) Assumptions and Parameter Values for Generic Assessment - Land Application: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Time spent indoors, adult (hr) living space, attic	 4380 48	 6570 72	Living space: typical estimate assumes indoor dust contact 12 hrs/day, all year; MEI assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months. Attic: Typical estimate assumes 12 days with soil on skin 4 hrs/day. MEI assumes 12 days with soil on skin 6 hrs/day.	Adopted from Hawley, 1985
Area of skin exposed outdoor, child (cm^2)	2100 cm^2	2800 cm^2	Typical estimate assumes both hands, legs and feet exposed during play; MEI estimate assumes both hands, arms, legs and feet exposed.	Hawley, 1985
Area of skin exposed outdoor, older child (cm^2)	1600 cm^2	3200 cm^2	Low assumes only hands exposed. Best estimate assumes both hands, forearms, legs from knees down exposed during play. High assumes both hands, legs and feet exposed during play.	Typical estimate: Hawley, 1985; MEI: assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	1700 cm^2	2940 cm^2	Typical: assumes both hands, most of forearms exposed; MEI: assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Typical estimate: Hawley, 1985; MEI: Schaum, 1984 (citing Sendroy, 1954)

Table 6.3.C. (con't.) Assumptions and Parameter Values for Generic Assessment - Land Application: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Area of skin exposed indoor, child (cm^2)	500 cm^2	2800 cm^2	Typical estimate assumes area exposed equals one half of surface area of childs feet, hands and forearms. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	400 cm^2	3200 cm^2	Typical estimate assumes only hands are exposed. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	900 cm^2 (living space) 1700 cm^2 (attic)	2940 cm^2 in both attic and living space	Typical estimate assumes hands exposed in living space, while adult wears short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat, to work in attic. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1}	0.024 h^{-1} (children only)	Typical: Bioavailability Workgroup. MEI: Hawley (1985) assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989; Hawley, 1985.
Availability of dioxin from soil matrix	1%	15%	Recommended value: 1%	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

TCDD and TCDF are significantly different from the mechanism of exposure upon which risk estimates were based; therefore, a dermal bioavailability factor is used for TCDD and TCDF. The generic analysis uses the same factors for dermal absorption of TCDD and TCDF as the site-specific analysis. A transfer coefficient of 0.012 h^{-1} is used in the estimate of typical exposure for all age groups, while in the MEI exposure analysis, a transfer coefficient of 0.024 hr^{-1} is used for both younger and older children.

6.3.2 Estimates of Exposure and Risks from Ingestion of Produce, Meat, and Dairy Products Grown on Sludge-Amended Land

Methodology

This section evaluates the risks from dietary exposure that may result from application of contaminated sludge to pasture and cropland. The methodology used in the generic assessment is identical to that used in the site-specific assessment. The methodology is described in Section 2.4.2. The calculations proceed in three steps. First, the model calculates tissue concentrations of contaminants in each crop as a result of the land application of sludge. Second, the model estimates concentrations of the contaminants in meat or dairy products. Contaminants are assumed to enter meat and dairy products as a result of animal ingestion of sludge-treated crops and pasture grasses and of direct ingestion of sludge adhering to pasture grasses. Third, the model sums the amount of each contaminant in all crops and animal products ingested by humans to estimate typical population exposure or MEI exposure.

Data Sources and Model Inputs

Data sources and model inputs for estimating dietary risk can be found in Table 6.3.D for both typical individuals and the MEI. Differences between the site-specific and generic assessments regarding sludge concentrations are discussed in Section 6.0. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Data Sources and Model Inputs for Sludge-amended Acreage, Crops Grown on Sludge-amended Land, and Percent of Crops Fed to Animals

Both the site-specific analysis and the generic analysis assume that 435 hectares of agricultural land receives TCDD-contaminated sludges. However, in the site-specific analysis, typical risks are calculated separately for the two states, Mississippi and Pennsylvania, in which sludge is applied agriculturally. A generic scenario for agricultural application was created by averaging the inputs,

Table 6.3.D. Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of cow's consumption that is soil (dry weight)	8%	8%		U.S. EPA (1988) "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Animal product yields:		N.A.		U.S. Dept. of Agriculture. Agricultural Statistics, 1987
lb beef/lb feed	0.07			
lb milk/lb feed	0.97			
lb hog/lb feed	0.17			
lb chicken/lb feed	0.40			
lb catfish/lb feed	0.5			
Percent of product that is fat:				Kimbrough et al., 1984 Wisconsin Human Exposure Assessment, 1989 NCASI, 6/87
beef	10	13		
milk	4	4		
hog	7	8		
chicken	10	10		
Fish filet concentration as a percent of whole body concentration	50	50		EPA - "Bioconcentration Factors for TCDD and TCDF", August, 1989

Table 6.3.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Animal consumption (% of total dry wt consumption)				US EPA "Human Health Risk Assessment for Municipal Sludge Disposal," 1989; Delta Western Feed Mill for catfish data
- corn				
beef	2	2		
dairy	8	8		
hogs	77	77		
chicken	59	59		
- soybeans				
catfish	50	50		
- pasture				
beef	38	38		
dairy	38	38		
Size of population over which produce is distributed	239,000,000	N.A.	Assumes national distribution	
Uptake rates - (dry weight)				EPA memo, Dioxins in Paper Work Group, 6/23/89
wheat	0.02	0.02		
corn	0.02	0.02		
grass	0.02	0.02		
soybeans	0.02	0.02		

Table 6.3.D. (cont.) **Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway**

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Fish BCF	1	10		U.S. EPA (1988), "Estimating Exposure to 2,3,7,8-TCDD," OHEA, Exposure Assessment Group (Draft)
Beef fat BCF (fresh weight)	4	6		Fries, 1982
Milk fat BCF (fresh weight)	4	5		Fries, 1982
Hog fat BCF (fresh weight)	4	6	Assumed to be equal to beef fat	
Chicken fat BCF (fresh weight)	4	6	Assumed to be equal to beef fat	
% dry matter				
grains	0.26	0.26		FDA "Reanalysis of FDA Revised Total Diet Food List" in EPA, "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge, 1986.
soybeans	0.08	0.08		
grass	0.05	0.05		

Table 6.3.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
% home grown	N.A.			U.S. EPA (1986), "Development of Risk Assessment Methodology for Land Application and Distribution and Marketing of Municipal Sludge."
grains		2		
legumes		17		
milk		40		
meat		44		
poultry, fish		34		
Consumption (mg/kg/day)	N.A.		Highest values for any age group are used for each food	U.S. EPA Office of Pesticide Program's Tolerance Assessment System dietary data base.
wheat		3,154		
corn		1,013		
beef fat		669		
dairy fat		1,424		
hog fat		425		
chicken		796		
soybean oil		1,359		
fish		394		
Total sludge area (ha)	435	N.A.		State contact: Bureau of Waste Management Wilkesbury, PA, Regional Office and Bureau of Pollution Control, MS Dept. of Environmental Quality
Amount of beef produced from sludge amended pasture (kgs)	5084	N.A.	Divided Perry and Forest Counties sludge-amended pasture by total pasture in the counties. Applied this percentage to marketed cows for the 2 counties. Multiplied by kilograms per cow.	County Extension Agent, Perry County; Bureau of Pollution Control MS Dept. of Environmental Quality; Agricultural Statistics, 1987

Table 6.3.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Crop yields (bushels/ha):		N.A.		
wheat	94			U.S. Department of Agriculture "Agricultural Statistics," 1985
corn	222			
soybean	59			
% of area producing:		N.A.		State contacts: Bureau of Pollution Control, Mississippi Dept. of Environmental Quality; County Extension Agent for Perry County, MS and Bureau of Waste Management, Wilkesbury, PA Regional Office
wheat	22%			
corn	33%			
soybeans	36%			
pasture	9%			
% wheat to animals	0	N.A.		County Extension Agent for Perry County, MS and Bureau of Waste Management, Wilkesbury, PA Regional Office
% corn to animals	92%	N.A.		
% soybeans to animals	40%	N.A.		
% of animal corn fed to:		N.A.		
beef cows	74%		MS: State contact said there are no commercial dairy cows though farmers may have them for own use. From agricultural statistics, multiplied beefs, hogs, and chickens in the state by the amount they each consumed. Summed to get total consumption and then took %'s consumed by beefs, hogs, chickens. PA: 100% of corn is assumed to be fed to dairy cows.	County Extension Agent for Perry County, MS; Harrisburg, PA Dept. of Agriculture; and Agricultural Statistics, 1987
hogs	3%			
chickens	1%			
dairy cows	22%			

Table 6.3.D. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
% of animal soybeans fed to catfish	100	N.A.	The MS county extension agent reports that approximately 50% of soybeans fed to animals serve as catfish feed. The remainder are fed to hogs, broilers and laying hens. In the absence of information on quantities fed to each animal and on the animal yield per unit soybean feed, all soybeans fed to animals are assumed to be fed to catfish	Perry County Extension Agent

N.A. = Not applicable.

weighted by land area, for Mississippi and Pennsylvania. In the generic scenario, the practices in the two states are combined and presented as though they were occurring at one site. Since the risk calculations do not depend on the location of the site, combining the site acreage does not affect risk.

Data Sources and Model Inputs for Animal Bioconcentration Factors

The rates at which animals incorporate TCDD in feed into their system is used to estimate contaminant concentrations in meat and dairy products. The animal bioconcentration factors (BCF) used for beef fat, milk fat, pork fat, and chicken fat differ between the site-specific and generic MEI analyses. A value of 4 is used for the BCF for each of these products in the site-specific MEI analysis. The generic MEI analysis conservatively uses the site-specific MEI "high estimates". The BCF values in the generic analysis are therefore 6 for beef fat, pork fat, and chicken fat and 5 for milk fat.

Both the typical and the MEI analyses use a different BCF for fish in the generic assessment than was used in the site-specific assessment. A fish BCF of 0.1 was used in the site-specific analysis for both the typical and MEI scenarios (U.S. EPA, 1989b). A BCF of 1 is substituted for 0.1 in the generic typical risk assessment; in the MEI generic assessment a BCF of 10 is input. The generic BCF values are based on a review of the literature on fish-to-sediment ratios presented by U.S. EPA (1988a). These values represent a more conservative estimate of risk than do the fish BCF's used in the site-specific assessment.

Data Sources and Model Inputs for MEI Dietary Consumption Rates

One of the inputs in calculating MEI exposure is the rate at which the MEI consumes foods of the type which may be contaminated. In both the site-specific and the generic analyses estimates of MEI dietary consumption are drawn from the U.S. EPA's Office of Pesticide Program's Tolerance Assessment System (TAS) dietary data base (U.S. EPA, 1987). TAS presents consumption rates for several age categories. In the site-specific analysis, the values chosen from TAS represent the consumption rates of a non-nursing infant. This age group was chosen since a non-nursing infant consumes a relatively large amount of food per unit of body weight. The MEI is assumed to maintain this rate of consumption throughout his entire lifetime.

An alternate set of consumption rates was used in the generic assessment. The generic assessment reviewed the TAS database to determine the age category for which the consumption rate of each contaminated food type was greatest on a per body weight basis. The MEI was assumed to consume each contaminated food type at this highest rate of consumption for his entire lifetime. This mixing of the consumption rates of different age groups may appear unrealistic and excessively conservative as a method of representing constant consumption rates over an individual's lifetime. However, the TAS database reports average consumption rates for each of the age groups and does not represent individuals with unusually high consumption rates per unit of body weight. Therefore, the conservative method described above was chosen to compensate for outlying high individual rates of consumption that are not represented by TAS data.

Data Sources and Model Inputs for Population to which Contaminated Produce is Distributed

To determine typical exposures, the total available quantity of contaminated food is divided by the population across which the crop or animal product is distributed. In the site-specific analysis, produce from Mississippi was assumed to be distributed nationally; produce from Pennsylvania was assumed to be distributed throughout the New England and Mid-Atlantic regions. In the generic assessment, all produce is assumed to be distributed nationally. This assumption does not affect population risk (e.g., cases per year) since the quantity of contaminated food is determined independently of the population exposed and risk is assumed to be a linear function of exposure.

6.3.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge

Methodology

Direct ingestion of soil can occur when sludge is applied to sites where people may live and work, such as a family farm. The calculations for estimating risks from direct ingestion of sludge contaminants are given in Section 2.4.3. Risk is estimated based on the daily quantity of soil and dust ingested and the slope factors of TCDD and TCDF.

Data Sources and Model Inputs Used to Estimate Exposure through Direct Ingestion of Sludge

The values used for each model input are summarized in Table 6.3.E for both the typical individual and the MEI. Section 2.4.3 describes each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. The following section describes other input values that differ from the site-specific analysis.

Table 6.3.E. Assumptions and Parameter Values for Generic Assessment - Land Application: Soil Ingestion Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Amount soil ingested, g/day	0.1	0.1	Single value used to represent average daily consumption throughout lifetime.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Percent of daily ingestion from outdoors	100%	100%	Typical and MEI: all soil is assumed to originate from outdoor sources.	
Amount of soil ingested from sludge-amended land	0.10	1.0	Typical value of 10% was used in evaluation of reuse of municipal sewage sludge. MEI: assumes all soil from sludge-amended land.	EPA, OWRS, "Human Health Risk Assessment for Municipal Sludge Disposal; Benefits of Alternative Regulatory Options," 1989.

Data Sources and Model Inputs for Soil Ingestion Rates

The memorandum "Interim Final Guidance for Soil Ingestion Rates" (EPA, 1989d) gives a suggested range of soil ingestion rates for children of 0.1 to 0.2 grams per day, with a maximum of 0.8 grams per day. The guidance memorandum suggests the use of 0.2 grams per day as a best estimate of daily soil ingestion for children. For adults, the guidance memorandum gives a range for adult soil ingestion of 0.001 to 0.1 grams per day. To simplify the calculation of risks from soil ingestion, and for consistency with other regulatory activities performed under RCRA, the generic analysis eliminates the separate consideration of children and adults and instead assumes a single ingestion rate of 0.1 grams per day to approximate a daily ingestion rate over an individual lifetime for both the typical and MEI generic scenarios.

Data Sources and Model Inputs for Fraction of Soil Ingested from Outdoor and Indoor Sources

The fraction of soil ingested indoors and outdoors is multiplied by the total daily ingestion rates used by EPA (1989d) to derive the quantities of soil ingested indoors and outdoors each day. Unlike in the site-specific assessment, where a fraction of soil was assumed to originate from indoor sources, the generic assessment assumes that all of the soil originates from outdoor sources for both the MEI and the typical exposure analyses.

6.3.4 Estimates of Exposures and Risks from Inhalation of Sludge-Contaminated Particulates

Methodology

TCDD and TCDF adhering to soil particles can become suspended in the air near a site treated with sludge. Transport downwind will dilute the concentration of particles from a treated area; these particles will also redeposit on surfaces. Farmers using pulp and paper mill sludge may be exposed to TCDD or TCDF by inhaling these particles.

The methodologies used in the site-specific and generic analyses of risks from inhaled particles are identical. To estimate the suspended particulate emissions at treated sites in the typical generic analysis, the methodology presented in Estimating Exposures to 2,3,7,8-TCDD (EPA, 1988a) is used. To obtain particulate concentration, the calculated emission rate is used as an input to a box model of atmospheric mixing. Both of these models are described in detail in Section 2.4.4 of this report.

As an alternative approach to estimating onsite particulate concentration, the model described by Hawley (1985) is applied for the MEI generic analysis; this model uses measured values of total suspended particles adjusted by the fraction of particles assumed to be derived from local (contaminated) soils to derive onsite concentrations of contaminated particles. The calculations required to used this method are also described in Section 2.4.4 of this report.

Data Sources and Model Inputs for Estimating Exposure through the Inhalation of Particles

The values used for each model input for the typical and MEI exposure estimates are summarized in Table 6.3.F. Section 2.4.4 describes each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. There are no other differences between the input values used in the site-specific and generic assessments.

6.3.5 Estimates of Exposure and Risks from Inhalation of Vapors

Methodology

Farmers land-applying contaminated sludge may incur risk from the inhalation of volatilized TCDD and TCDF. The methodology for estimating the emissions of TCDD and TCDF vapor at agricultural land application sites in the generic assessment is identical to that used in the site-specific assessment. The methodology generally follows methods for estimating volatilization described in EPA (1988a).

The calculation of risks from the inhalation of vaporized TCDD and TCDF requires first the estimation of emissions, then the calculation of indoor and outdoor onsite concentrations. Because actual locations of the homes using composted sludge are not known, the ISCLT model could not be used to estimate downwind concentrations. As a result, this analysis estimates only exposures to onsite residents (i.e., farmers), using a box model to obtain the onsite concentrations from the emissions estimates. The concentrations are combined with data on time spent indoors and outdoors, respiration rate and slope factors of TCDD and TCDF to obtain the estimated cancer risk from this pathway of exposure. These calculations are described in detail in Section 2.4.5.

Data Sources and Model Inputs for Estimating Exposure through the Inhalation of Vapor

Table 6.3.F. summarizes key assumptions and input parameters for estimating typical and MEI exposure through the vapor and particulate inhalation pathways. Differences between generic and

Table 6.3.F. Assumption and Parameter Values for Generic Assessment - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Typical estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation; MEI: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Percent TSP respirable	NA	0.90	Typical estimate for emissions is from Eq. 6-11 (EPA, 1988), which gives estimates of small (<10 um) particle emissions. All of these particles are assumed to be respired. Therefore, this parameter applies only to TSP, which consists of large and small particles (i.e., this parameter applies only to the MEI estimate of emissions).	Hawley, 1985
Fraction of TSP to lung	1/3 of respired particles	0.90 (100% of respired particles)	Typical: one-third of respired particles found in lungs; MEI: assumes 100% of contaminant adhering to respired particles absorbed through lung.	Schaum, 1984 (citing ICRP, 1968)
Fraction of TSP to GI tract	2/3 of respired particles	0% of respired particles	Typical: 2/3 of respired particles in GI; MEI: assumes all particles absorbed through lung.	Schaum, 1984 (citing ICRP, 1968)
Absorption rate, lung	1.0		Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 6.3.F. (con't.) Assumption and Parameter Values for Generic Assessment - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Hours per day and number of days spent outdoors, adult	12 hrs/day 130 days	12 hrs/day 130 days	Typical and MEI: 6 months, 5 days/wk, 12 hrs/day.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	8 hrs/day 130 days	12 hrs/day 182 days	Typical: assumes child plays outdoors 8 hrs/day, May-October, 5 days per wk; MEI: assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	5 hrs/day 152 days	12 hrs/day 152 days	Typical: assumes child plays outdoors an average of 5 hrs/day, May-September; MEI: assumes 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult attic, living space	12 hrs/yr, in attic; 12 hrs/day, 130 days plus 24 hrs/day, 235 days	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic; Living space: Typical and MEI: 12 hrs/day in living space for 130 days in summer months plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 6.3.F. (con't.) Assumption and Parameter Values for Generic Assessment - Land Application: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	16 hrs/day, 130 days, plus 24 hrs/day, 235 days	12 hrs/day 182 days, plus 24 hrs/day 182 days	MEI: assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day; Typical: assumes indoors 16 hrs/day, 5 days/wk during May-October, indoors 24 hrs/day for remainder of days. (Note: MEI indoor estimate coupled with MEI outdoor estimate.)	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	16 hrs/day for 365 days	12 hrs/day for 365 days, 12 hrs/day, 152 days, plus 24 hrs/day, 213 days	MEI: assumes child is indoors 12 hrs/day, 7 days/wk, 24 hr/dy for 5 months. Typical: assumes child is indoors an average 16 hrs/day; other hours spent outdoors or at school. (Note: MEI indoor estimate coupled with outdoor MEI estimate.)	Adopted from Hawley, 1985
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 80% outdoor	Indoor = 100% outdoor	Typical: From Hawley, 1985; MEI estimate is maximum value possible.	Hawley, 1985

site-specific sludge concentration assumptions are discussed in Section 6.0. There are no other differences between the input values used in the site-specific and generic assessments.

6.3.6 Estimates of Exposure and Risks from Ingestion of Drinking Water from Surface Water Sources

In the site-specific assessment, the typical risks resulting from land application of contaminated sludge were reported as an average of the seven land application sites. The MEI risk reported was the highest risk resulting from land application at any one site. This generic assessment, however, distinguishes between risks resulting from agricultural application of sludge and risks resulting from silvicultural and mine reclamation applications. Typical risks are reported separately for agricultural application and for silvicultural and mine reclamation applications. Two MEI risks are also reported: one representing the highest risks from agricultural application and the second representing the highest risks from silvicultural or mine reclamation application.

Methodology

The methodology used for the generic assessment is identical to that used for the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.4.7. In general, the Universal Soil Loss Equation, together with estimates of sediment delivery ratios, is used to estimate the fraction of a lake's or stream's sediment that originates from the land application site. By multiplying this fraction by the original concentration of TCDD and TCDF in sludge or soil particles on the sludge management area (SMA) surface, the methodology derives estimates of the concentration of contaminants in the sediment. This contaminant load is then partitioned between adsorbed and dissolved phases. Contaminant concentrations in water are combined with data on human rates of water ingestion, the size of the population exposed, and slope factors to yield exposure and risk estimates.

Data Sources and Model Inputs

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 6.3.G (for agricultural application) and Table 6.3.H (for silvicultural and mine application) for both typical individuals and the MEI. Differences between the site-specific and generic assessments regarding the assumed sludge concentrations were discussed in Section 6.0. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Table 6.3.G. Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
"C" ratio Agriculture	4	6	See text.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
"P" ratio Agriculture	0.75	1	Typical: assumes contouring; MEI assumes no support practices.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
Distance from site to surface water (meters)	30	30	Pennsylvania permit limit. (only data point received for agricultural application)	Pennsylvania regional environmental office
Drainage Area (ha)	1,295,000	4,047	Typical: scenario assumes the sites drain into a major waterway. MEI: scenario assumes the sites drain into a relatively small stream.	
Percent Organic Carbon in Soil	0.01	0.001		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)

Table 6.3.G. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100		
Fish to sediment ratio				U.S. EPA "Estimating Exposure 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group (Draft)
- Dioxin	1	10		
- Furan	1	10		
Fish consumption (grams/day)	6.5	140	Includes fresh water and estuarine fish and shellfish.	Typical: U.S. EPA "Estimating Exposure 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group (Draft) MEI: U.S. EPA Office of Water
Percent of fish consumed by the exposed population that is contaminated	100	100		

Table 6.3.G. (cont.) Assumptions and Parameter Values for Generic Assessment - Agricultural Application: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA memo, "Bioconcentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	68	N.A.	U.S. average population density.	U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	49	N.A.	National average.	USGS National Water Survey
Sludge-amended area (hectares per year)	435 (2 sites)	405 (1 site)		From each state's environmental department's permit data or environmental offices' best estimate.

Notes: N.A. = Not applicable.

Table 6.3.H. Assumptions and Parameter Values for Generic Assessment - Silvicultural and Mine Reclamation Applications: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
"C" ratio	1:1	1:1	See text.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
"P" ratio	1:1	1:1	Assumes no support practices.	"Predicting Rainfall Erosion Losses," USDA Handbook #537
Distance from site to surface water (meters)	1,355	46	Typical: average of 3 estimated values (3218, 801, 46); MEI: lowest estimated value.	State environmental offices
Drainage Area (ha)	1,295,000	4,047	Typical: scenario assumes the sites drain into a major waterway. MEI: scenario assumes the sites drain into a relatively small stream.	
Percent Organic Carbon in Soil	0.01	0.001		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)
Water Consumption (liters/day)	2	2		U.S. EPA, "Estimating Exposure to 2,3,7,8 TCDD" (1988), OHEA Exposure Assessment Group (Draft)

Table 6.3.H. (cont.) Assumptions and Pararster Values for Generic Assessment - Silvicultural and Mine Reclamation Applications: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of water consumed by the exposed population that is contaminated	100	100		
Fish to sediment ratio				
- Dioxin	1	10		U.S. EPA "Estimatirg Exposure 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group (Draft)
- Furan	1	10		
Fish consumption (grams/day)	6.5	140	Includes fresh water and estuarine fish and shellfish.	Typical: U.S. EPA "Estimating Exposure 2,3,7,8-TCDD" (1988), OHEA, Exposure Assessment Group (Draft) MEI: U.S. EPA Office of Water
Percent of fish consumed by the exposed population that is contaminated	100	100		

Table 6.3.H. (cont.) Assumptions and Parameter Values for Generic Assessment - Silvicultural and Mine Reclamation Applications: Surface Water Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Concentration in filet vs. concentration in whole fish	0.5	0.5		U.S. EPA memo, "Bioconcentration Factors for 2,3,7,8-TCDD and TCDF," August, 1989
Population density (people/square mile)	68	N.A.	U.S. national population density.	U.S. Department of Commerce. "U.S. Statistical Abstracts," (1987)
Percent of Population served by surface water	49	N.A.	National average.	USGS National Water Survey
Sludge-amended area (hectares per year)	1,805 (5 sites)	1,012	Typical: 361 hectares is the average reported area of the 5 sites; the 5 sites were assessed separately and the risks were added. MEI: largest reported area.	From each state's environmental department's permit data or environmental offices' best estimate.

Notes: N.A. = Not applicable.

Data Sources and Model Inputs for Calculating Sediment Concentration

As explained in Appendix B, the parameters necessary to calculate sediment concentration (before partitioning) from soil concentration are: SMA area, SMA sediment delivery ratio, drainage area, drainage area sediment delivery ratio, and the Universal Soil Loss Equation parameters. New values are used for the SMA area and the SMA sediment delivery ratio in the generic assessment.

In the site-specific analysis, the area of each sludge-amended site was combined with other site-specific parameters to determine the risks presented by each site. The site that resulted in the highest individual risk was used to represent the MEI scenario. For the generic MEI assessment, the largest reported SMA area from the site-specific analysis is used to calculate risk. For silvicultural and mine reclamation applications, the sludge management area is assumed to be 1,012 hectares. For the generic assessment of MEI risks from agricultural land application, the largest reported land application are, 405 acres, is used.

The second input variable that differs between the two analyses is the SMA sediment delivery ratio. This ratio is a function of the distance between the SMA and the nearest body of surface water. In the site-specific analysis, distances specific to each state were used. In the generic assessment, representative values were chosen for the two types of land application. For the assessment of typical and MEI risks from agricultural land application, the generic assessment used a distance of 30 meters. This was the only distance estimate reported for agricultural application. and corresponds to the State of Pennsylvania's permitted limit for distance between a SMA and a drainage way. The distance between the SMA and surface water used in estimating the typical risk from silvicultural and mine reclamation application is an average of three distances obtained from states in which current SMAs are believed to be located. These values reflect either a permit limit on distance or an estimate of actual distance between the SMA and surface water. The distance is assumed to equal 1,355 meters. For the MEI risk estimate for silvicultural and mine reclamation applications, the smallest of the three estimates of distance, 46 meters, was used.

Data Sources and Model Inputs for Deriving the Partition Coefficient

Koc, the partition coefficient between water and organic carbon, is multiplied by the fraction of organic carbon in the sediment to obtain Kd, the partition coefficient between sediment and water. In the site-specific assessment the MEI "best estimate" assumes a one percent organic carbon content.

The generic MEI assessment assumes a 0.1 percent organic carbon content. The effect of this change will be a decrease in the sediment contamination level and an increase in the water contamination level.

Data Sources and Model Inputs for Estimating the Size of the Exposed Population

In the site-specific analysis, the size of the exposed population was estimated by multiplying the watershed area of the contaminated stream by the population density of the regions in which the SMAs were located. In the generic analysis, a national population density (68 people per square mile) replaces the regional population density.

6.3.7 Estimates of Exposure and Risks from Ingestion of Fish from Surface Water Sources

Methodology

The methodology used for the generic assessment is identical to that used for the site-specific assessment. Details of the methods used for these calculations are presented in Appendix B and Section 2.4.7. The calculation follows those presented in Section 6.3.6 through the estimation of sediment concentrations of TCDD and TCDF in water bodies as a result of runoff from land application sites. Once sediment concentrations have been estimated, however, the methodology departs from that described in Section 6.3.6, and uses fish-to-sediment bioconcentration factors and estimates of human consumption of fish to calculate contaminant doses to humans. The estimate of the size of the exposed population is combined with estimates of individual dose and health risk to derive total health risks to the entire exposed populations.

Data Sources and Model Inputs

Data sources and model inputs for estimating sediment and water contaminant concentrations can be found in Table 6.3.G (agricultural applications) and Table 6.3.H (silvicultural and mine reclamation applications) for both typical individuals and the MEI. Differences between the site-specific and generic assessments regarding assumed sludge concentrations are discussed in Section 6.0. Differences regarding sediment:water partition coefficient, the site sediment delivery ratio, the area of the SMA, and the size of the exposed population are presented in Section 6.3.6. Additional differences between the generic assessment and the site-specific assessment are discussed below.

Data Source and Model Inputs for Estimating the Fish to Sediment Bioconcentration Factor

Both the site-specific analysis and the generic analysis calculate bioaccumulation in fish as a function of a fish-to-sediment bioconcentration factor. In the site-specific analysis of typical and MEI risk the bioconcentration factors used for TCDD and TCDF were 0.0967 and 0.1538, respectively (U.S. EPA, 1989b). Based on a review of fish to sediment bioconcentration factors by U.S. EPA (1988a), a fish-to-sediment ratio of 1:1 is used in the generic analysis of typical risk. This value is used for both TCDD and TCDF. The fish bioconcentration factor used in the generic MEI assessment also differs from the value used in the site-specific MEI assessment. A fish-to-sediment ratio of 10:1 is used in the generic assessment (U.S. EPA, 1988a).

Data Sources and Model Inputs for the Rate of Human Consumption of Fish

Although the generic and site-specific assessments use the same rate of fish consumption to calculate typical exposure, the consumption rates differ for the MEI calculations. A consumption rate of 100 grams day was used in the site-specific assessment (U.S. EPA, 1988b). This consumption rate reflected the upper 90th percentile ingestion rate of freshwater fish by sport fishers in the Great Lakes area. In the generic assessment, the MEI is assumed to be a subsistence fisher consuming freshwater fish at the rate of 140 grams per day (U.S. EPA Office of Water).

6.3.8 Summary of Results

The estimates of typical and MEI exposure and health risks from the land application of paper mill sludge containing TCDD and TCDF are summarized in Tables 6.3.I and 6.3.J. The tables indicate that the greatest risk to the MEI is presented by the consumption of fish contaminated by surface runoff. Consumption of contaminated fish results in risks on the order of 10^{-1}. The pathway presenting the second greatest risk to the MEI is consumption of produce grown in contaminated soil; ingestion of contaminated drinking water also results in a relatively high MEI risk.

In contrast to the MEI, the typical individual is exposed to the greatest risk through inhalation of volatilized TCDD and TCDF. The risks to a typical individual from inhalation of volatilized TCDD and TCDF are estimated as 1×10^{-5}. This risk is an order of magnitude lower than the risk to the MEI through volatilization, and about four orders of magnitude lower than the risk to the MEI through any exposure pathway.

The pathways resulting in the largest number of annual cancer cases for the entire U.S. population are, in order of contribution to magnitude: consumption of contaminated fish, ingestion

Table 6.3.1. Human Exposure Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Dermal exposure from contact with soil contaminated by land application of sludge:	3×10^{-10}	(62)	2×10^{-12}	(65)
Exposure from direct ingestion of soil contaminated by land application of sludge:	3×10^{-10}	(62)	8×10^{-12}	(65)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge:	1×10^{-9}	(4)	8×10^{-11}	(4)
Inhalation exposure to particulates from soil contaminated by land application of sludge:	3×10^{-11}	(65)	5×10^{-12}	(65)
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by agricultural land application of sludge:	1×10^{-8}	(0.6)	2×10^{-12}	(0.6)

Table 6.3.1. (con't.). Human Exposure Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge to mines and forests:	2×10^{-8}	(0.6)	2×10^{-12}	(0.6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge:	$<2 \times 10^{-12}$	(0.2)	$<2 \times 10^{-12}$	(0.2)
Ingestion exposure to fish caught in surface water contaminated by runoff from areas contaminated by agricultural land application of sludge:	8×10^{-7}	(63)	3×10^{-12}	(65)
Ingestion exposure to fish caught in surface water contaminated by runoff from areas contaminated by application of sludge to mines/forests:	1×10^{-6}	(63)	3×10^{-12}	(65)
Dietary exposure from produce grown in soil contaminated by land application of sludge:	7×10^{-8}	(62)	1×10^{-15}	(65)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

Table 6.3.J. Human Health Risk Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-5} (62)	3×10^{-7} (65)	40	2×10^{-7} (65)
Exposure from direct ingestion of soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-5} (62)	1×10^{-6} (65)	40	7×10^{-7} (65)
Inhalation exposure to air contaminated by volatilization from soil contaminated by land application of sludge: (Percent TCDD)[c]	2×10^{-4} (4)	1×10^{-5} (4)	40	7×10^{-6} (4)
Inhalation exposure to particulates from soil contaminated by land application of sludge: (Percent TCDD)[c]	4×10^{-6} (62)	7×10^{-7} (65)	40	4×10^{-7} (65)
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by agricultural land application of sludge: (Percent TCDD)[c]	2×10^{-3} (0.6)	3×10^{-7} (0.6)	333,000	1×10^{-3} (0.6)

Table 6.3.J. (con't.). Human Health Risk Estimates from Land Application of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Ingestion exposure from drinking surface water contaminated by surface runoff from soil contaminated by land application of sludge to mines/forests: (Percent TCDD)[c]	3×10^{-3} (0.6)	3×10^{-7} (0.6)	833,000	4×10^{-3} (0.6)
Ingestion exposure from drinking groundwater contaminated by leaching from soil contaminated by land application of sludge: (Percent TCDD)[c]	$<6 \times 10^{-7}$ (0.2)	$<6 \times 10^{-7}$ (0.2)	NA[d]	NA[d]
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by agricultural land application of sludge: (Percent TCDD)[c]	1×10^{-1} (63)	5×10^{-7} (65)	679,000	4×10^{-3} (65)
Ingestion exposure to fish contaminated by surface runoff from areas contaminated by application of sludge to mines/forests: (Percent TCDD)[c]	2×10^{-1} (63)	5×10^{-7} (65)	1,700,000	1×10^{-2} (65)
Dietary exposure from produce grown in soil contaminated by land application of sludge: (Percent TCDD)[c]	1×10^{-2} (62)	2×10^{-10} (65)	240,000,000	7×10^{-4} (65)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5 x 10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\,[\text{Exposure to TCDF}]}$

[d] Not applicable.

of contaminated surface water, and consumption of produce grown from contaminated soil.

The risks are dominated by TCDD for all pathways except the volatilization, surface water and groundwater pathways. TCDF is more significant in determining risk than TCDD for these pathways due to its greater volatility and solubility.

6.4 Exposure and Risks from Distribution and Marketing of Pulp and Paper Sludge

Sludge that is composted and marketed can be used as a soil amendment in residential settings as well as for agricultural and commercial purposes. As in the site-specific analysis, the generic analysis estimates risks to members of households using composted sludge from the following routes of exposure:

- Home gardeners incorporate distributed and marketed sludge to home gardens. The home-grown crops incorporate small amounts of contaminant into their tissues. Household residents then consume the home-grown crops.

- Home gardeners incorporate distributed and marketed sludge into their home gardens, or use it for other home gardening purposes, such as lawns or flower beds. Children and adults in the gardening household come into direct dermal contact with the sludge. TCDD and TCDF from the sludge is absorbed through the skin.

- Children ingest small amounts of the sludge/soil mixture through normal mouthing behavior. Adults also inadvertently ingest small quantities of sludge/soil.

- TCDD and TCDF in distributed and marketed sludge volatilizes from the sludge into the air. Residents of the household inhale the volatilized TCDD and TCDF.

- Distributed and marketed sludge is applied to home gardens or other home uses. Particles of the sludge/soil mixture become suspended in the air. Members of the household inhale the contaminated particles.

There are few differences between the site-specific assessment and the generic assessment, since a "generic" distribution and marketing scenario had to be constructed in the site-specific assessment to estimate risks from the distribution and marketing of sludge from plants currently engaged in this use practice. In the generic scenario, a household uses composted sludge as a soil amendment for ornamental or vegetable gardening. For a complete discussion of the scenario and of the data sources used to construct the scenario, the reader is referred to Section 2.5. The estimated soil concentrations used in the generic assessment for typical and MEI exposure analyses are shown in Table 6.4.A. Methods used to derive soil concentrations are described in Appendix A of this report. As this table shows, the generic assessment assumes that the typical gardener soil-incorporates sludge, while the MEI gardener does not. Other parameters that describe the generic scenario, as well as the physical/chemical parameters of TCDD and TCDF used in the assessment of several of the exposure pathways, are presented in Table 6.4.B.

The following sections describe the methods and data used to estimate risks from home uses of distributed and marketed sludge through each these pathways. Results are summarized in the final section.

6.4.1 Estimates of Exposure and Risks from Dermal Contact with Skin

Methodology

Risks from dermal exposure are calculated as a function of the amount of soil in contact with the skin, the length of time the soil remains on the skin, and the dermal absorption rate. The methods used to estimate risks from dermal contact with sludge-contaminated soil are described in Section 2.5.1.

Data Sources and Model Inputs

The values used for each model input for typical and MEI exposure estimates are summarized in Table 6.4.C. A description of these input parameters, and a discussion of the basis for selecting input parameter values, are found in Section 2.5.1. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. There are no other differences between the input values used in the site-specific and generic assessments. It is important to note that in other pathways considered in the generic assessment, the bioavailability of TCDD is assumed to be 100%. However, dermal absorption of TCDD and TCDF are significantly different from the mechanism of exposure upon which risk estimates were based; therefore, a dermal bioavailability factor is used for TCDD and TCDF. The generic analysis uses the same factors for dermal absorption of TCDD and TCDF as the site-specific analysis. A transfer coefficient of 0.012 hr^{-1} is used in the estimate of typical exposure for all age groups, while in the MEI exposure analysis, a transfer coefficient of 0.024 hr^{-1} is used for both younger and older children.

Table 6.4.A. Distribution and Marketing Sludge and Soil Contaminant Concentrations Used in Generic Assessment[*]

Contaminant	Mean sludge concentration	90th percentile sludge concentration	Estimate for Typical Individual: Soil concentration using mean conc., and assuming 6 inches (15 cm) depth of incorporation	Estimate for MEI: Soil concentration using 90th percentile conc. assuming no soil incorporation
TCDD	163	293	10	293
TCDF	885	1760	55	1760

---

[*] average concentrations over 70 years of exposure, assuming sludge is applied to land for 20 years

Table 6.4.B. Parameters and Model Inputs Used to Model Distribution and Marketing for Generic Assessment

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Percent of sludge to home garden vs. other uses	50%	100%	Typical estimate: based on analysis of National Garden Survey, 1987; MEI: maximum value possible.	National Garden Survey, 1987
Soil Incorporation Assumptions	6 inches	0 inches		USDA "Use of Sewage Sludge Compost for Soil Improvement and Plant Growth." ARM-NE-6, August 1979.
Garden Size (hectares)	0.016	0.022		National Garden Survey (1987)
Application Rate (DMT/year)	10	20		USDA (1979)

Table 6.4.B. (cont.) Parameters and Model Inputs Used to Model Distribution and Marketing for Generic Assessment

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDD diffusivity in air (cm^2/sec)	0.05	0.05		Eduljee (1987); U.S. EPA (1988).
TCDD diffusivity in water (cm^2/sec)	5.5×10^{-6}	5.5×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDD solubility in water (ug/g)	0.02	0.02	TCDD concentrations do not reach solubility limit in model simulations.	Marple et al. (1986) at 22°C.
TCDD photolysis half life of vapor (min)	4,320	4,320		Mill (1985); Atkinson (1987).
TCDD molecular weight	322	322		
TCDD Koc (cm^3/g)	1×10^7	1×10^7		Jackson (1985) as reported in U.S. EPA (1987).
TCDD Henry's Law Constant atm m^3/mol	1.6×10^{-5}	1.6×10^{-5}		Best estimate and high estimate values from Podol (1986); low estimate from U.S. EPA (1987).

Table 6.4.B. (cont.) Parameters and Model Inputs Used to Model Distribution and Marketing for Generic Assessment

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
TCDF diffusivity in air (cm^2/sec)	0.05	0.05	Estimated with Wilke and Lee method.	Lyman et al. (1982).
TCDF diffusivity in water (cm^2/sec)	5.6×10^{-6}	5.6×10^{-6}	Estimated with Hayduk and Laudie method.	Lyman et al. (1982).
TCDF solubility in water (ug/g)	4.3	4.3	TCDF concentrations do not reach solubility limit in model simulations.	CHEMEST procedure in GEMS
TCDF photolysis half life of vapor (min)	4,320	4,320	Assumed same as TCDD.	Mill (1985); Atkinson (1987).
TCDF molecular weight	306	306		
TCDF Koc	3.5×10^4	3.5×10^4		Value from ChemEst procedure in GEMS, using Kenaba method.
TCDF Henry's Law Constant atm m^3/mol	8.6×10^{-5}	8.6×10^{-5}		ChemEst procedure in GEMS.

Table 6.4.C. Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Contact rate mg/cm^2 outdoor, child	0.5	1.5	Roels (1980) used in Schaum (1984) to develop MEI value; Lepow (1975) cited by Schaum for typical estimate value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, older child	0.5	1.5	Roels (1980) used in Schaum (1980) for MEI value; Lepow (1975) cited by Schaum for typical estimate value.	Schaum, 1984 Hawley, 1985
Contact rate mg/cm^2, outdoor, adult	3.5	3.5	Typical and MEI estimate: value from Hawley (1985) based on adults doing yard work.	Hawley, 1985
Contact rate mg/cm^2, indoor, child	0.056	0.06	MEI value from Solomon and Hartord (1976) as cited by Hawley. Typical estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, older child	0.056	0.06	MEI value from Solomon and Hartord (1976) as cited by Hawley. Typical estimate value from Hawley, assuming dust fall indoors = 20% outdoors, with cleaning every two weeks.	Hawley, 1985
Contact rate mg/cm^2, indoor, adult, living space,	0.056	0.06	Contact rate for adults in living space same as for children; for work in attic, Hawley, 1985, developed a value of 1.8 mg/cm^2 for direct contact; for indirect contact with dusty air, Hawley estimated contact as 110 mg for 1 hour of attic work.	Hawley, 1985
indoor, adult attic	1.8 (110 mg/hr)			

Table 6.4.C. (cont.) Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Ratio of contaminant concentration indoors to soil concentration outdoors	0.80	0.85		Hawley, 1985
Time spent outdoors, child (hr)	1565	2190	Typical estimate: assumes 5 days/wk, 6 months/yr, 12 hrs/day (12 hrs before soil is washed off); MEI: assumes 7 days/wk, 6 months/yr, 12 hrs/day soil contact.	Adopted from Hawley, 1985
Time spent outdoors, older child (hr)	1824	2190	Typical: child outdoors from May to September every day (150 days), 12 hrs of soil contact before washing; MEI estimate: child outdoors every day for 6 months, 12 hrs soil contact.	Adopted from Hawley, 1985
Time spent outdoors, adult (hr)	348	1565	Typical: assumes 8 hrs of soil contact before washing, 2 days/wk for 5 months; MEI estimate: assumes 12 hrs soil contact before washing, 5 days/wk, 6 months/yr (130 days).	Typical: Hawley, 1985; MEI: Adopted from Keenan, 1989
Time spent indoors, child (hr)	4380	6570	Typical: 12 hrs/day of indoor dust contact all year; MEI assumes 24 hrs/day of indoor dust contact for 6 winter months, plus 12 hrs/day for 6 summer months.	Adopted from Hawley, 1985 and Keenan, 1989

Table 6.4.C. (cont.) Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Time spent indoors, older child (hr)	1460	4380	Typical: assumes 4 hrs/day of indoor dust contact all year; MEI: assumes 12 hrs/day of indoor dust contact all year.	Adopted from Hawley, 1985
Time spent indoors, adult (hr)			Living space: Typical estimate assumes indoor dust contact 12 hrs/day, all year; MEI: assumes indoor dust contact 24 hrs/day, 6 winter months, plus 12 hrs/day, 6 summer months.	Adopted from Hawley, 1985
living space,	4380	6570		
attic	48	72	Attic: Typical estimate assumes 12 days with soil on skin 4 hrs/day. MEI: assumes 12 days with soil on skin 6 hrs/day.	
Area of skin exposed outdoor, child (cm^2)	2100 cm^2	2800 cm^2	Typical estimate assumes both hands, legs and feet exposed during play; MEI: assumes both hands, arms, legs and feet exposed.	Hawley, 1985
Area of skin exposed outdoor, older child (cm^2)	1600 cm^2	3200 cm^2	Typical estimate assumes both hands, forearms, legs from knees down exposed during play; MEI: assumes both hands, legs and feet exposed during play.	Typical estimate: Hawley, 1985; MEI: assumption from Keenan, 1989; surface area values from Hawley, 1985
Area of skin exposed outdoor, adult (cm^2)	1700 cm^2	2940 cm^2	Typical: assumes both hands, most of forearms exposed. MEI: assumes adult is wearing short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat.	Typical estimate: Hawley, 1985; MEI: Schaum, 1984 (citing Sendroy, 1954)

Table 6.4.C. (cont.) Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Dermal Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Area of skin exposed indoor, child (cm^2)	500 cm^2	2800 cm^2	Typical estimate assumes area exposed equals one half of surface area of of childs feet, hands and forearms. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, older child (cm^2)	400 cm^2	3200 cm^2	Typical estimate assumes only hands are exposed. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Area of skin exposed indoor, adult (cm^2)	900 cm^2 (living space) 1700 cm^2 (attic)	2940 cm^2 in both attic and living space	Typical estimate assumes hands exposed in living space, while adult wears short-sleeved shirt, with an open neck, pants, shoes, no gloves or hat, to work in attic. MEI assumes area exposed indoors same as outdoors.	Hawley, 1985
Bioavailability through skin	0.012 h^{-1}	0.024 h^{-1} (children only)	Typical: Bioavailability Workgroup. MEI: Hawley (1985) assumed that skin of children has twice the absorption of adults.	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989; Hawley, 1985.
Availability of dioxin from soil matrix	1%	15%	Recommended value: 1%	"Common Assumptions for the Assessment of Human Dermal Exposure to Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans," memo from Mike Babich, CPSC, July 6, 1989.

6.4.2 Estimates of Exposure from Ingestion of Home-Grown Produce

Methodology

Risks through the dietary pathway are calculated by estimating the contaminant concentration in homegrown crops, and then multiplying this concentration by the daily consumption of home-grown vegetables. This analysis assumes that only the residents of the household using the composted sludge are exposed to sludge contaminants. Furthermore, the analysis assumes that home gardeners do not produce meat or dairy products with the distributed and marketed sludge. A detailed description of the calculations for this pathway is found in Section 2.5.2 of this report.

Data Sources and Model Inputs for Estimates of Exposure from Ingestion of Home-Grown Produce

The values used for each model input for the typical and MEI dietary exposure estimates are summarized in Table 6.4.D. Section 2.5.2 of this report describes each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Section 6.0 describes differences between generic and site-specific sludge concentration assumptions. The following discussion describes other input parameters that differ from those used in the site-specific analysis.

Data Sources and Model Inputs for Plant Uptake Rates

Unlike the site-specific assessment, the generic assessment uses the same crop TCDD uptake rates for both the typical and MEI analyses. Uptake rates for all home-grown crops except potatoes and root crops were estimated to be 2 percent; root crops are assumed to take up 50 percent of the TCDD and TCDF in the soil. These values are based on the data presented by the Subgroup on TCDD Uptake in Terrestrial Plants (EPA, 1989d). The root crop value assumes that the vegetable is eaten whole; that is, the vegetable is washed but is not peeled before it is eaten.

Data Sources and Model Inputs for Adult and Child Daily Food Consumption Rates

This analysis assumes that the quantity and types of food consumed by those who have home gardens is the same as for those who do not have home gardens. This assumption allows the use of the TAS Dietary Database (U.S. EPA, 1987), which provides average U.S. dietary consumption values for various age groups. Since the distribution and marketing model estimates risks to children age 1-6 separately from adults, consumption values for both adults and children must be selected. The overall U.S. average consumption values were used for adults in the typical distribution and

Table 6.4.D. Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Dietary Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Plant uptake rates	above-ground: 0.02 root: 0.5	above-ground: 0.02 root: 0.5	Value for whole roots is from the range recommended by Subgroup on Dioxin Update in Terrestrial Plants (memo from Christina Cinalli, June 23, 1989).	Values for above-ground and root vegetables: Subgroup on Dioxin Uptake in Terrestrial Plants (6/23/89 memo).
Fraction of vegetables from home garden	0.27 for all vegetables but legumes; 0.15 potatoes; 0.07 dried legumes.	0.6 for all vegetables but legumes; 0.45 potatoes; 0.17 dried legumes.	Values are based on USDA Survey, 1966, as cited in USEPA, 1988. Typical estimate values represent rural, non-farm households; MEI represents rural, farm households.	EPA OWRS. Technical Support Document for the Land Application and Distribution and Marketing of Sewage Sludge. August, 1988.
Adult and child consumption rates	Values based on TAS Dietary Database	Values based on TAS Dietary Database	Typical: used average consumption values. values. MEI: used maximum consumption values for each food group.	TAS Dietary Database.

marketing generic analysis, while the values for children 1-6 were used for that age group. For the MEI analysis, the highest consumption value among all of the age groups listed in TAS was used for both children and adults for each food type. This mixing of the consumption rates of different age groups may appear unrealistic and excessively conservative as a method of representing constant consumption rates over an individual's lifetime. However, the TAS database reports average consumption rates for each of the age groups and does not represent individuals with unusually high consumption rates per unit of body weight. Therefore, the conservative method described above was chosen to compensate for outlying high individual rates of consumption that are not represented by TAS data.

6.4.3 Estimates of Exposure and Risks from Direct Ingestion of Sludge

Methodology

Direct ingestion of soil can occur when sludge is applied to sites where people live, such as a gardening household. The calculations for estimating risks from direct ingestion of sludge contaminants are given in Section 2.5.3. Risk is estimated based on the daily quantity of soil and dust ingested and the slope factors of TCDD and TCDF.

Data Sources and Model Inputs Used to Estimate Exposure through Direct Ingestion of Sludge

The values used for each model input are summarized in Table 6.4.E for both the typical individual and the MEI. Section 2.5.3 describes each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. The following section describes other input values that differ from the site-specific analysis.

Data Sources and Model Inputs for Soil Ingestion Rates

The memorandum "Interim Final Guidance for Soil Ingestion Rates" (EPA, 1989d) gives a suggested range of soil ingestion rates for children of 0.1 to 0.2 grams per day, with a maximum of 0.8 grams per day. The guidance memorandum suggests the use of 0.2 grams per day as a best estimate of daily soil ingestion for children. For adults, the guidance memorandum gives a range for adult soil ingestion of 0.001 to 0.1 grams per day. To simplify the calculation of risks from soil ingestion, and for consistency with other risk assessments performed under RCRA, the generic analysis eliminates the separate consideration of children and adults and instead assumes a single

Table 6.4.E. Assumptions and Parameter Values for Generic Assessment - Distribution and Marketing: Soil Ingestion Pathway

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Amount soil ingested, g/day,	0.1	0.1	Single value used to represent average daily consumption over lifetime.	OSWER Directive 9850.4 "Interim Final Guidance for Soil Ingestion Rates," J. Winston Porter, January 27, 1989
Percent of daily ingestion from outdoors, child	100%	100%	Analysis assumes 100% of soil from outdoor sources.	
Amount of soil ingested from sludge-amended land	0.10	1.0	Typical Value of 10% was used in evaluation of reuse of municipal sewage sludge. MEI values arbitrary.	EPA, OWRS, "Human Health Risk Assessment for Municipal Sludge Disposal; Benefits of Alternative Regulatory Options," 1989.

ingestion rate of 0.1 grams per day to approximate a daily ingestion rate over an individual lifetime for both the typical and MEI generic scenarios.

Data Sources and Model Inputs for Fraction of Soil Ingested from Outdoor and Indoor Sources

The fraction of soil ingested indoors and outdoors is multiplied by the total daily ingestion rates used by EPA (1989d) to derive the quantities of soil ingested indoors and outdoors each day. Unlike in the site-specific assessment, where a fraction of soil was assumed to originate from indoor sources, the generic analysis assumes that all of the soil originates from outdoor sources for both the MEI and the typical exposure analyses.

6.4.4 Estimates of Exposures and Risks from Inhalation of Sludge-Contaminated Particulates

Methodology

TCDD and TCDF adhering to soil particles can become suspended in the air near a site treated with sludge. Transport downwind will dilute the concentration of particles from a treated area; these particles will also redeposit on surfaces. Residents using composted pulp and paper mill sludge on their home gardens may be exposed to TCDD or TCDF by inhaling these particles.

The methodologies used in the site-specific and generic analyses of risks from inhalation of particles are identical. To estimate the suspended particulate emissions at treated sites in the typical generic analysis, the methodology presented in Estimating Exposures to 2,3,7,8-TCDD (EPA, 1988a) is used. To obtain particulate concentration, the calculated emission rate is used as input to a box model of atmospheric mixing. Both of these models are described in detail in Section 2.5.4 of this report.

As an alternative approach to estimating onsite particulate concentration, the model described by Hawley (1985) is applied for the MEI generic analysis; this model uses measured values of total suspended particles adjusted by the fraction of particles assumed to be derived from local (contaminated) soils to derive onsite concentrations of contaminated particles. The calculations required to used this method are also described in Section 2.5.4 of this report.

Data Sources and Model Inputs for Estimating Exposure through the Inhalation of Particles

The values used for each model input for the typical and MEI exposure estimates are summarized in Table 6.4.F. Section 2.5.4 describes each input and documents the data sources used to derive the values for the parameters for both the typical and MEI analyses. Differences between generic and site-specific sludge concentration assumptions are discussed in Section 6.0. There are no other differences between the input values used in the site-specific and generic assessments.

6.4.5 Estimates of Exposure and Risks from Inhalation of Vapors

Methodology

Residents using distributed and marketed sludge may incur risk from the inhalation of volatilized TCDD and TCDF. The methodology for estimating the emissions of TCDD and TCDF vapor at residential sites in the generic assessment is identical to that used in the site-specific assessment. The methodology generally follows methods for estimating volatilization described in EPA (1988a).

The calculation of risks from the inhalation of vaporized TCDD and TCDF requires first the estimation of emissions, then the calculation of indoor and outdoor onsite concentrations. Because actual locations of the homes using composted sludge are not known, the ISCLT model could not be used to estimate downwind concentrations. As a result, this analysis estimates only exposures to onsite residents, using a box model to obtain the onsite concentrations from the emissions estimates. The concentrations are combined with data on time spent indoors and outdoors, respiration rate and slope factors of TCDD and TCDF to obtain the estimated cancer risk from this pathway of exposure. These calculations are described in detail in Section 2.5.5 of this report.

Data Sources and Model Inputs for Estimating Exposure through the Inhalation of Vapor

Table 6.4.F. summarizes key assumptions and input parameters for estimating typical and MEI exposure through the vapor and particulate inhalation pathways. Section 6.0 discusses differences between generic and site-specific sludge concentration assumptions. There are no other differences between the input values used in the site-specific and generic assessments.

Table 6.4.F. Assumption and Parameter Values for Generic Assessment - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Method for calculating particulate emissions	Eq 6-11, 50% vegetative cover	assume 50% of total TSP from local soil	Typical estimate: calculated using Eq. 6-11 from EPA, 1988 assuming 50% vegetation. MEI: following Hawley, assume 50% of total TSP from local soil; local TSP = 64 ug/m^3.	EPA, 1988 Hawley, 1985
Indoor TSP concentration as function of outdoor TSP concentration	0.75	0.85		Hawley, 1985 (citing Sterling and Kobayashi, 1977 and Whitby et al., 1957)
Percent TSP respirable	NA	0.90	Typical estimates for emissions is from Eq. 6-11 (EPA, 1988), which gives estimates of small (<10 um) particle emissions. All of these particles are assumed to be respired. Therefore, this parameter applies only to TSP, which consists of large and small particles (i.e., this value applies only to MEI estimate of emissions).	Hawley, 1985
Fraction of TSP to lung	1/3 of respired particles	1/3 of respired particles	Typical: one-third of respirable particles is initially found in lungs; MEI: all respired contaminant adhering to particles absorbed through lung.	Schaum, 1984 (citing ICRP, 1968)
Fraction of TSP to GI tract	2/3 of respired particles	5/6 of respired particles	Typical: 2/3 in G.I. tract; MEI: assumes all absorbed through lung.	Schaum, 1984 (citing ICRP, 1968)
Absorption rate, lung	1.0	1.0	Value from Bioavailability Workgroup and Keenan, 1989. This value is applied to the particles that reach the alveoli.	Memorandum from F.J. DiCarlo, HERD, to G. Schweer, June 16,1989

Table 6.4.F. (cont.) Assumption and Parameter Values for Generic Assessment - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Hours per day and number of days spent outdoors, adult	8 hrs/day 40 days	12 hrs/day 130 days	Typical: assumes adult works 2 days per wk, 5 months/yr, 8 hr/day; MEI: assumes adult works 6 months, 5 days/wk, 12 hrs/day.	Adopted from Hawley 1985
Hours per day and number of days spent outdoors, child	8 hrs/day 130 days	12 hrs/day 182 days	Typical: assumes child plays outdoors 8 hrs/day, May-October, 5 days per wk; MEI: assumes child plays outdoors 12 hrs/day, May-October, 7 days per wk.	Adopted from Hawley, 1985
Hours per day and number of days spent outdoors, older child	5 hrs/day 152 days	12 hrs/day 152 days	Typical: assumes child plays outdoors an average of 5 hrs/day, May-September; MEI: assumes 12 hrs/day, May-September.	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, adult: attic, living space	12 hrs/yr, in attic; 16 hrs/day, 365 days in living space	12 hrs/yr in attic; 12 hrs/day, 130 days plus 24 hrs/day 235 days	Attic: assumed that adult spends 12 hrs/yr (either 1 day for 12 hrs or 1 hr for 12 days) in attic. Typical: 16 hrs/day, 365 days in living space; MEI: 12 hrs/day in living space for 130 days in summer months plus 24 hrs/day in living space for rest of year.	Adopted from Hawley, 1985

Table 6.4.F. (cont.) Assumption and Parameter Values for Generic Assessment - Distribution and Marketing: Vapor and Particulate Inhalation Pathways

Input parameter	Estimate for typical individual	Estimate for MEI	Notes/explanation	Reference
Hours per day and number of days spent indoors, child	16 hrs/day, 130 days, plus 24 hrs/day, 235 days	12 hrs/day, 182 days, plus 24 hrs/day, 182 days	MEI: assumes child plays indoors 12 hrs per day, 7 days per wk during May-October, rest of year indoors 24 hrs per day. Typical: assumes indoors 16 hrs/day, 5 days/wk during May-October, indoors 24 hrs/day for remainder of days. (Note: MEI estimate is coupled with MEI estimate for outdoors.)	Adopted from Hawley, 1985
Hours per day and number of days spent indoors, older child	16 hrs/day for 365 days	12 hrs/day, 152 days plus 24 hrs/day for 213 days	MEI: assumes child is indoors 12 hrs/day, 5 months, 7 days/wk; Typical: assumes child is indoors an average 16 hrs/day. (Note: MEI estimate for indoors is coupled with MEI estimate for outdoors.)	Adopted from Hawley, 1985
Indoor contaminant concentration as function of outdoor contaminant concentration	Indoor = 80% outdoor	Indoor = 100% outdoor	Typical: From Hawley, 1985; MEI estimate is maximum value possible.	Hawley, 1985

6.4.6 Summary of Results

The estimates of typical and MEI exposure and health risks from the distribution and marketing of paper mill sludge containing TCDD and TCDF are summarized in Tables 6.4.G and 6.4.H. These tables show that the pathway of exposure posing the greatest health risk to a typical individual is the direct ingestion pathway. The typical daily exposure through the direct ingestion of soil is approximately 2×10^{-12} mg/kg/day. This exposure results in a risk of 3×10^{-7}, or approximately 1×10^{-2} cancer cases per year, based on an estimated exposed population of 3,500,000 persons.

Dietary exposures pose the lowest risks. The typical daily exposure estimated for this pathway is 3×10^{-16} mg/kg/day. This exposure leads to an individual typical risk of 4×10^{-11}, and an estimated 2×10^{-6} cases per year. Dietary risks are low because plants take up relatively little TCDD and TCDF from the soil.

In general, risks for the "most exposed individual" (MEI) are two to three orders of magnitude higher than the risks for a typical individual. Estimated risks for the MEI are lowest for the particle inhalation and dietary pathways, and are highest for the pathways involving direct human contact with contaminated soil (i.e., the dermal and direct ingestion pathways). The greatest MEI risk is posed by the dermal pathway. The MEI daily exposure through the dermal contact pathway is approximately 8×10^{-10} mg/kg/day. This exposure results in a risk of 1×10^{-4}.

In all pathways examined in the distribution and marketing scenario except volatilization, TCDD contributes more to risk than TCDF. However, for the vapor inhalation pathway, TCDF contributes almost all of the risk, because it is more easily volatilized than TCDD.

Table 6.4.G. Human Exposure Estimates from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI exposure[a] (mg/kg/day)	(% TCDD)[b]	Typical exposure[a] (mg/kg/day)	(% TCDD)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge:	8×10^{-10}	(63)	2×10^{-13}	(59)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge:	7×10^{-10}	(57)	2×10^{-12}	(56)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge:	4×10^{-12}	(5)	3×10^{-13}	(6)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge:	1×10^{-12}	(64)	3×10^{-14}	(71)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge:	1×10^{-13}	(62)	3×10^{-16}	(71)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + 1/10 of estimated exposure to 2,3,7,8-TCDF.

[b] Calculated as:

$$100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$$

Table 6.4.H. Human Health Risk Estimates from Distribution and Marketing of Pulp and Paper Sludges Contaminated with 2,3,7,8-TCDD and 2,3,7,8-TCDF

Exposure pathway	MEI risk[a] (per lifetime)	Typical risk[a] (per lifetime)	Exposed population	Total risk (cases/year)[b]
Dermal exposure from contact with soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-4} (63)	3×10^{-8} (59)	3,500,000	1×10^{-3} (59)
Exposure from direct ingestion of soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	1×10^{-4} (57)	3×10^{-7} (56)	3,500,000	1×10^{-2} (56)
Inhalation exposure to air contaminated by volatilization from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	6×10^{-7} (5)	4×10^{-9} (6)	3,500,000	2×10^{-3} (6)
Inhalation exposure to particulates from soil contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-7} (64)	4×10^{-9} (71)	3,500,000	2×10^{-4} (71)
Dietary exposure from produce grown in gardens contaminated by distributed and marketed sludge: (Percent TCDD)[c]	2×10^{-8} (62)	4×10^{-11} (71)	3,500,000	2×10^{-6} (71)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5

[b] Calculated as: [Typical Risk x Exposed Population] / [Life Expectancy]

[c] Calculated as: $100 \times \frac{\text{[Exposure to TCDD]}}{\text{[Exposure to TCDD]} + (1/10)\ \text{[Exposure to TCDF]}}$

6.5 CONCLUSIONS

6.5.1 Discussion of Results

Tables 6.5.A and 6.5.B present the maximum exposure and risk associated with each disposal or use method. These tables show that the greatest MEI risks from landfills, surface impoundments, and land application are of a similar magnitude. In each case, the greatest MEI risk is posed by the fish ingestion pathway of exposure. For distribution and marketing (where fish ingestion was not considered as a potential exposure pathway), the greatest risks are associated with direct ingestion and dermal contact with sludge-amended soil.

The greatest typical individual risk is a result of inhalation of TCDD and TCDF that volatilized from sludge applied agriculturally. Volatilized TCDD and TCDF from land applied sludge presents risks that are nearly two orders of magnitude greater than highest typical individual risk resulting from other sludge disposal methods.

The four disposal or use pathways yield very similar total population risks, differing by less than a factor of three. As with MEI risks, the pathway posing the greatest total population risk for landfills, surface impoundments, and land application is consumption of contaminated fish. The pathway resulting in the greatest total population risk for distribution and marketing is direct ingestion of contaminated soil.

6.5.2 Comparison with Site-specific Assessment

Table 6.5.C compares the risks estimated in the site-specific MEI assessment to those estimated in the generic MEI assessment, while Table 6.5.D compares the typical risks estimated in the two assessments. The MEI risks estimated using the generic scenarios are, for the most part, quite similar to those generated in the site-specific assessment. The generic MEI analysis provides risk estimates approximately an order of magnitude or more different from the site-specific analysis for the following exposure pathways: volatilization at landfills and surface impoundments; ingestion of fish contaminated by runoff from landfills and land application sites; ingestion of groundwater contaminated by landfills and surface impoundments; direct ingestion of soil at land application sites; and ingestion of water contaminated by runoff from land application sites. Many of the differences are attributable to the differences in the TCDD and TCDF soil concentrations assumed. Table 6.5.E displays the soil concentrations assumed for each of the disposal methods in the site-specific MEI assessment and compares them to the soil concentrations assumed in the generic MEI assessment. The direction and magnitude of the differences between the concentrations assumed correspond well

Table 6.5.A. Maximum Exposure to TCDD and TCDF by Waste Re-Use or Disposal Method

Exposure Pathway	MEI Exposure[a,b] (mg/kg/day)	(% TCDD)[c]	Typical Exposure[a,d] (mg/kg/day)	(% TCDD)[c]
Potential Human Exposure from Disposal of Pulp and Paper Sludge In Landfills	3×10^{-7}	(63)	5×10^{-13}	(65)
Potential Human Exposure from Disposal of Pulp and Paper Sludge in Surface Impoundments	7×10^{-7}	(63)	7×10^{-13}	(65)
Human Exposure from Land Application of Pulp and Paper Sludge	1×10^{-6}	(63)	8×10^{-11}	(4)
Human Exposure from Distribution and Marketing of Pulp and Paper Sludge	8×10^{-10}	(63)	2×10^{-12}	(56)

Notes:

[a] Equals estimated exposure to 2,3,7,8-TCDD + one tenth of estimated exposure to 2,3,7,8-TCDF.

[b] Represents highest exposure to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method.

[c] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

[d] Represents highest typical exposure through any single exposure pathway associated with this waste disposal or re-use method.

Table 6.5.8. Maximum Human Health Risks from Exposure to TCDD and TCDF, by Waste Management Method

Exposure Pathway	MEI risk[a,b] (per lifetime)	Typical risk[a,c] (per lifetime)	Exposed population[d]	Total risk (cases/year)[e]
Potential human exposure from disposal of pulp and paper sludge in landfills (percent TCDD)[f]	5×10^{-2} (63)	8×10^{-8} (65)	14,200,000	2×10^{-2} (65)
Potential human exposure from disposal of pulp and paper sludge in surface impoundments (percent TCDD)[f]	1×10^{-1} (63)	1×10^{-7} (65)	4,760,000	7×10^{-3} (65)
Human exposure from land application of pulp and paper sludge (percent TCDD)[f]	2×10^{-1} (63)	1×10^{-5} (4)	1,700,000	1×10^{-2} (65)
Human exposure from distribution and marketing of pulp and paper sludge (percent TCDD)[f]	1×10^{-4} (63)	3×10^{-7} (56)	3,500,000	1×10^{-2} (56)

Notes:

[a] Calculated as: [Estimated Exposure] x 1.5×10^5

[b] Represents highest risk to "most exposed individual" through any single exposure pathway associated with this waste disposal or re-use method.

[c] Represents highest risk to typical exposed individual for any single exposure pathway for this disposal or reuse method.

[d] Total exposed population for single exposure pathway associated with highest total risks for this sludge re-use or disposal method. Does not necessarily correspond to size of population exposed to highest typical individual risk.

[e] Calculated as: [Typical Risk for the pathway x Exposed Population for the pathway] / [Life Expectancy]

[f] Calculated as: $100 \times \frac{[\text{Exposure to TCDD}]}{[\text{Exposure to TCDD}] + (1/10)\ [\text{Exposure to TCDF}]}$

Table 6.5.C. Comparison of Site-Specific and Generic MEI Risk Estimates

Disposal method	Pathway	Site-specific MEI risk (lifetime-1)	(%TCDD)	Generic MEI risk (lifetime-1)	(%TCDD)	Ratio of generic to site-specific risk estimate	Ratio of generic to site-specific % TCDD
Landfill	Volatilization	3 x 10-9	(<0.01)	4 x 10-7	(4.03)	143.0	20150.0
	Drinking surface water	1 x 10-3	(0.15)	7 x 10-4	(0.59)	0.7	3.9
	Fish ingestion	2 x 10-3	(21.55)	5 x 10-2	(63.19)	28.4	2.9
	Groundwater	8 x 10-9	(0.53)	1 x 10-9	(2.08)	0.1	3.9
Surface Impoundment	Volatilization	3 x 10-5	(0.77)	1 x 10-6	(0.62)	0.1	0.8
	Drinking surface water	6 x 10-3	(0.77)	2 x 10-3	(0.60)	0.3	0.8
	Fish ingestion	2 x 10-2	(58.40)	1 x 10-1	(63.12)	6.0	1.1
	Groundwater	6 x 10-7	(0.50)	3 x 10-8	(0.40)	0.1	0.8
Land Application	Dermal contact	2 x 10-4	(99.97)	4 x 10-5	(62.37)	0.3	0.6
	Direct ingestion	4 x 10-4	(99.97)	4 x 10-5	(62.42)	0.1	0.6
	Volatilization	2 x 10-5	(99.98)	2 x 10-4	(4.01)	7.7	0.04
	Particulates	5 x 10-6	(99.99)	4 x 10-6	(62.45)	0.7	0.6
	Drinking surface water*	1 x 10-4	(13.06)	3 x 10-3	(0.59)	22.5	0.05
	Fish ingestion*	4 x 10-3	(96.52)	2 x 10-1	(63.18)	47.7	0.7
	Produce	2 x 10-2	(100.00)	1 x 10-2	(62.41)	0.6	0.6
Distribution and Marketing	Dermal contact	8 x 10-5	(35.25)	1 x 10-4	(62.50)	1.5	1.8
	Direct ingestion	2 x 10-4	(35.27)	1 x 10-4	(57.14)	0.5	1.6
	Volatilization	8 x 10-7	(1.35)	6 x 10-7	(4.76)	0.8	3.5
	Particulates	1 x 10-7	(35.36)	2 x 10-7	(64.29)	2.0	1.8
	Produce	1 x 10-8	(35.27)	2 x 10-8	(61.54)	1.5	1.7

* Surface water risks estimated in site-specific assessment compared to higher of agriculture and mine/forest surface water risks estimated in generic assessment.

Table 6.5.D. Comparison of Site-Specific and Generic Typical Risk Estimates

Disposal method	Pathway	Site-specific typical risk (lifetime-1)	(%TCDD)	Generic typical risk (lifetime-1)	(%TCDD)	Ratio of generic to site-specific risk estimate	Ratio of generic to site-specific % TCDD
Landfill	Volatilization	8 x 10-13	(<0.01)	1 x 10-9	(4.44)	1466.7	13320.0
	Drinking surface water	5 x 10-8	(0.42)	5 x 10-8	(0.64)	1.0	1.5
	Fish ingestion	7 x 10-9	(42.75)	8 x 10-8	(64.82)	11.0	1.5
	Groundwater	1 x 10-10	(5.61)	1 x 10-10	(8.42)	1.0	1.5
Surface Impoundment	Volatilization	2 x 10-7	(0.83)	4 x 10-8	(0.65)	0.2	0.8
	Drinking surface water	3 x 10-7	(0.84)	7 x 10-8	(0.65)	0.2	0.8
	Fish ingestion	6 x 10-8	(60.19)	1 x 10-7	(64.85)	1.9	1.1
	Groundwater	2 x 10-9	(0.87)	5 x 10-10	(0.68)	0.2	0.8
Land Application	Dermal contact	3 x 10-6	(99.99)	3 x 10-7	(64.77)	0.1	0.6
	Direct ingestion	4 x 10-7	(99.87)	1 x 10-6	(64.74)	3.2	0.6
	Volatilization	7 x 10-6	(99.96)	1 x 10-5	(4.43)	1.8	0.04
	Particulates	3 x 10-6	(100.00)	7 x 10-7	(64.81)	0.2	0.6
	Drinking surface water*	5 x 10-8	(6.35)	6 x 10-7	(0.64)	12.0	0.1
	Fish ingestion*	5 x 10-8	(92.27)	1 x 10-6	(64.90)	19.6	0.7
	Produce	2 x 10-8	(100.00)	2 x 10-10	(64.80)	0.01	0.6
Distribution and Marketing	Dermal contact	1 x 10-8	(38.29)	3 x 10-8	(58.82)	1.8	1.5
	Direct ingestion	6 x 10-8	(38.30)	3 x 10-7	(55.56)	4.4	1.5
	Volatilization	4 x 10-8	(1.54)	5 x 10-8	(6.25)	1.2	4.0
	Particulates	1 x 10-9	(38.36)	4 x 10-9	(71.43)	4.1	1.9
	Produce	2 x 10-11	(38.33)	4 x 10-11	(71.43)	2.6	1.9

* Surface water risks estimated in site-specific assessment compared to sum of agriculture and mine/forest surface water risks estimated in generic assessment.

Table 6.5.E. Comparison of Contaminant Soil Concentrations Used in Site-Specific and Generic MEI Assessments

Disposal method	Site-specific TCDD conc.	Site-specific TCDF conc.	Site-specific TCDD-equivalent conc.	Generic TCDD conc.	Generic TCDF conc.	Generic TCDD-equivalent conc.	Ratio of generic/ site-specific TCDD conc.	Ratio of generic/ site-specific TCDF conc.	Ratio of generic/ site-specific TCDD-equivalent concentration
Landfill	293	6740	967	293	1760	469	1.0	0.3	0.5
Surface impoundment	3800	17100	5510	293	1760	469	0.1	0.1	0.1
Land application - all pathways but drinking water and fish ingestion	330	1	330.1	107	645	171.5	0.3	645.0	0.5
Land application - drinking water and fish ingestion	330	106	340.6	293	1760	469	0.9	16.6	1.4
Distribution & Marketing	60.7	1113	172	293	1760	469	4.8	1.6	2.7

to the direction and approximate magnitude of the differences between risk estimates for many of the exposure pathways analyzed. Estimates of volatilization, groundwater, and surface water risks are especially sensitive to differences in the assumed TCDF concentrations, since TCDF is the more mobile than TCDD in water and in air. For example, the lower risks from groundwater ingestion at landfills and surface impoundments are attributable to the lower TCDF concentrations assumed for these disposal practices in the MEI generic assessment. The higher TCDF concentrations assumed for land application sites contribute to the higher risks estimated from drinking water contaminated by runoff from land application sites. However, there are other important differences between the site-specific and generic assessments that influence the differences in risk. The most dramatic difference between site-specific and generic estimated risks is between the site-specific and generic risks estimated from volatilization at landfills. The generic estimates are higher than the site-specific estimates because the Hwang and Falco (1986) model, rather than SESOIL, was used to estimate emissions; furthermore, the generic assessment did not assume that landfills are covered. Generic risk estimates from other pathways are also influenced by changes in model assumptions. For example, in the MEI assessment for landfills, surface impoundments, and land application sites, the fish ingestion risks are higher in the generic assessment despite lower assumed soil concentrations: the higher risk is attributable to the substantially higher fish-to-sediment bioconcentration factor assumed in the generic assessment. Risks from direct ingestion at land application sites are lower in the generic assessment as a result of differences in assumptions regarding TCDD soil concentration and daily soil ingestion rate.

As with MEI risks, few of the typical risk estimates differ dramatically between the site-specific and generic risk assessments, with the notable exception of volatilization risks from landfilling. For the typical analysis, the following risks estimated in the generic assessment are an order of magnitude or more different than risks estimated in the site-specific assessment: the risks from volatilization at landfill sites; the risks from ingestion of fish contaminated by runoff from landfills; the risks from dermal contact at land application sites; risks from ingestion of fish and ingestion of drinking water contaminated by runoff at land application sites; and risks from ingestion of produce grown in land-applied sludge. As discussed above, the generic estimates of volatilization risks from landfills are higher than site-specific estimates because of the difference in the model used and because of the difference in the assumption regarding cover. Many of the other differences between the generic and site-specific estimates of typical risks can be explained by differences in the soil concentrations assumed in each assessment. Table 6.5.F displays soil concentrations assumed for the site-specific and generic typical assessments. For example, the generally lower risks from surface impoundments in the generic assessment correspond to lower TCDD and TCDF concentrations. The comparison is not straightforward for land application and distribution and marketing. In the site-specific typical analysis, risks were estimated separately for the several plants

Table 6.5.F. Comparison of Contaminant Soil Concentrations Used in Site-Specific and Generic Typical Assessments

Disposal method	Site-specific TCDD conc.	Site-specific TCDF conc.	Site-specific TCDD-equivalent conc.	Generic TCDD conc.	Generic TCDF conc.	Generic TCDD-equivalent conc.	Ratio of generic/ site-specific TCDD conc.	Ratio of generic/ site-specific TCDF conc.	Ratio of generic/ site-specific TCDD-equivalent concentration
Landfill	62	520	114	163	885	251.5	2.63	1.70	2.21
Surface impoundment	501	2087	709.7	163	885	251.5	0.33	0.42	0.35
Agricultural application									
MS	330	0	330.0	34.6	188	53.4	0.1	NA	NA
PA	4	1	4.1	34.6	188	53.4	8.7	188.0	13.0
Mine/forest application									
GA	181	501	231.1	163	885	251.5	0.9	1.8	1.1
ME	1	5	1.5	163	885	251.5	163.0	177.0	167.7
MD	80	471	127.1	163	885	251.5	2.0	1.9	2.0
OH	145	795	224.5	163	885	251.5	1.1	1.1	1.1
WI	9	106	19.6	163	885	251.5	18.1	8.3	12.8
Distribution & Marketing									
CA	3.8	69	10.7	10.1	54.6	15.6	2.7	0.8	1.5
PA	0.1	0.07	0.1	10.1	54.6	15.6	101.0	780.0	145.4
WA	0.3	3.2	0.6	10.1	54.6	15.6	33.7	17.1	25.1
OH	1.1	15	2.6	10.1	54.6	15.6	9.2	3.6	6.0
PA	0.9	2.8	1.2	10.1	54.6	15.6	11.2	19.5	13.2
TX	1.1	15	2.6	10.1	54.6	15.6	9.2	3.6	6.0
TX	0.2	0.5	0.3	10.1	54.6	15.6	50.5	109.2	62.2

that land apply and distribute and market sludge. The TCDD and TCDF sludge concentrations assumed in the generic assessment are higher than the concentrations assumed for some of the plants in the site-specific assessment, and lower than the concentrations assumed for other plants. The direction and magnitude of differences in the risk estimates will depend on the how the generic assessment differs from the site-specific assessment for each plant.

The generic assessment estimates higher fish ingestion risks for every disposal method for which this pathway was considered. These results are attributable to the difference in the fish-to-sediment bioconcentration factor assumed.

REFERENCES FOR CHAPTER 6

Hawley, J.K. (1985). Assessment of health risk from exposure to contaminated soil. Risk Analysis 5(4):289-302.

U.S. EPA (1987). "Comparison of Food Consumption Data". Tolerance Assessment Program, Office of Pesticides and Toxic Substances. Washington, D.C.

U.S. EPA (1988a). Estimating Exposures to 2,3,7,8-TCDD. Office of Health and Environmental Assessment, EPA/600/6-88/005A. External Review Draft, March.

U.S. EPA (1988b). Risk Assessment for Dioxin Contamination, Midland, Michigan. EPA-905/4-88-005.

U.S. EPA (1989a). 104-Mill Data Base. Office of Water Regulations and Standards, July 17 version.

U.S EPA (1989b). Memorandum: "OTS/EEB Aquatic Life Hazard (Including BCF Values) for 'Dioxins in Paper'". Office of Pesticides and Toxic Substances. Washington, D.C. August.

U.S. EPA (1989c). Memorandum to Dioxin-in-Paper Workgroup, on the bioavailability of dioxins in paper products, dated June 23 from C. Cinalli and Conrad Flessner.

U.S. EPA (1989d). "Interim Final Guidance for Soil Ingestion Rates." Office of Solid Waste Emergency Response Directive Number 9850.4, January 27 from J. Winston Porter.

Appendix A. Methods for Calculating Soil Concentrations

Assessing risks from exposure to TCDD and TCDF from the land application of contaminated sludge requires the calculation of long-term average contaminant concentrations in the soil to which the sludge is applied. The long-term average concentration in the soil will depend on the initial sludge concentrations, the depth of soil incorporation (if any), the frequency of application, and the decay rate of TCDD and TCDF in soil. Because of uncertainty regarding decay processes of TCDD and TCDF, this analysis conservatively assumes that decay will be insignificant.

Two methods of sludge application will be considered:

- application of sludge as top dressing (without soil incorporation), and
- incorporation of sludge into a layer of soil.

The following discussion describes the calculation of average TCDD and TCDF concentrations in the soil over specified exposure periods for each of these scenarios. To aid the reader, an example calculation of TCDD concentration in soil receiving sludge in Mississippi is included in Appendix E.

Soil Concentration Calculation for Top-dressed Sludge

Top-dressed sludge may be limited to a one-time application or may be applied repeatedly to the same plot of land. In either case, when sludge is land applied without soil incorporation, the sludge replaces the top soil. Concentrations in soil in all top-dressing scenarios are assumed to equal concentrations in the land-applied sludge. Humans are assumed to be exposed to the TCDD and TCDF concentration levels for 70 years after the sludge is applied.

Soil Concentration Calculation for Soil Incorporated Sludge

When sludge is incorporated into the soil, soil concentrations are dependent on the depth of sludge incorporation into uncontaminated soil, frequency of application, and initial sludge concentration. The calculations to determine soil concentration proceed in two steps:

Step One: Estimating the Mass of Contaminant Added and the Mass of Receiving Soil

The mass of the contaminant added is calculated by multiplying the application rate by the contaminant concentration:

$$MC = \frac{A\ CC}{1 \times 10^{12}}$$

where:

A = Sludge application rate (kg/ha/year);

CC = Contaminant concentration in sludge (ppt);

MC = Mass of contaminant added (kg/ha/year).

The volume of soil with which the sludge is mixed is determined by multiplying the incorporation depth by the incorporation area. The volume is then multiplied by the soil density, assumed to be 1.8 grams/cm^3, to obtain the mass of the soil with which the sludge is incorporated:

$$MS = ID\ IA\ SD\ /\ 1{,}000$$

where:

IA = Area of soil incorporation of the sludge (cm^2/ha);

ID = Depth of incorporation of the sludge (cm);

MS = Mass of soil with which the sludge is incorporated (kg/ha); and

SD = Soil density (g/cm^3).

Step Two: Estimating Average Soil Concentrations

Average soil concentrations for a given year are estimated by adding the mass of contaminant applied to the land that year to the mass of contaminant present in the soil from previous sludge applications. This total contaminant mass is then divided by the mass of the receiving soil plus the mass of the applied sludge:

$$CY = \frac{1{,}000{,}000\ MC + (MS\ CP/1{,}000{,}000)}{MS + A}$$

where:

CP = Mass of contaminant present in soil before addition of sludge in any year (mg/kg); and

CY = Concentration of contaminant in soil in any year (mg/kg).

Note that CP and CY will increase with each year's application, but that they can never exceed the concentrations of TCDD and TCDF in the sludge.

Average soil concentrations for a land application site depend on the period over which application occurs. Concentrations will increase with each year's application, but they are assumed to remain constant (without decay processes) from the final application until the end of the exposure period. The average contaminant concentration in soil during the application period is calculated as follows:

$$CD = \left(\sum_{i=1}^{n} CY_i\right)/n$$

where:

CD = Average contaminant concentration in soil during the application period (mg/kg); and

n = Number of years that sludge is applied, equal to or less than 70.

The contaminant concentration in the soil at the end of the application period is defined as follows.

$$CE = CY_i$$

where:

CE = Concentration of contaminant in soil at the end of the application period (mg/kg); and

i = The last year of sludge application.

This analysis assumes that humans are exposed to TCDD and TCDF in the soil for 70 years, beginning with the first year of application. Sludge concentrations are averaged over the years of sludge application and any remaining non-application years in the 70 year exposure period:

$$CA = \frac{(n\ CD + (70-n)\ CE)}{70}$$

where:

CA = Average concentration over 70 year period of exposure (mg/kg).

Appendix B. Estimating TCDD and TCDF Concentrations in Surface Water and Fish

Where pulp and paper sludge is deposited in uncovered landfills or surface impoundments, and where sludge is land-applied, particles of surface soil may be contaminated with TCDD and TCDF from the sludge. If this contaminated soil then erodes from the sludge management area, adsorbed TCDD and TCDF may be transported to nearby surface water bodies. This appendix describes a methodology for estimating the extent of this type of over-land transport of TCDD and TCDF, and for estimating contaminant concentrations in sediment, surface water and fish tissue that could be expected to result. Data inputs for these calculations are listed in Tables 2.1.A, 2.1.B, 2.1.L, and 2.1.M for landfills, 2.3.A, 2.3.B, 2.3.G, and 2.3.H for surface impoundments, and 2.4.A, 2.4.B, 2.4.M, and 2.4.N for land application sites. To aid the reader, an example calculation of risk resulting from consumption of fish in included in Appendix E.

Contaminant concentrations in fish and drinking water are influenced by both the quantity of contaminants reaching surface water bodies and the extent of their dilution. Levels of exposure are therefore likely to differ from location to location. Areas where the largest quantities of sludge are applied, where concentrations of contaminants in the sludge are high, or where the quantity of or distance to receiving water is lowest are likely to have the highest concentrations of sludge contaminants in surface water. Where actual site-specific data are not available, this analysis uses a range of hypothetical scenarios to capture the range of uncertainty in exposure estimates.

Because of their tendency to adsorb to solid particles, TCDD and TCDF do not readily dissolve in surface runoff, and are not easily transported over land in dissolved phase. EPA's SARAH model (U.S. EPA, 1988a) can determine in-stream concentrations of chemical substances downstream SMAs, and was considered for assessing water and sediment concentrations that might result from contaminants released from pulp and paper landfills, surface impoundments, or land application sites. The SARAH model considers only the over-land transport of contaminants in dissolved phase, however, and does not include algorithms for estimating soil erosion and transport of adsorbed contaminants to surface water bodies. Since TCDD and TCDF are both hydrophobic, this latter mechanism is probably of more importance with respect to its potential for transport of the two contaminants. Use of SARAH to model transport of TCDD and TCDF from sludge management areas would probably result in the underestimation of sediment and fish concentrations in nearby water bodies.

This analysis therefore concentrates on the transport of TCDD and TCDF adsorbed to eroding soil particles. The methodology consists of three steps. First, it estimates expected soil concentrations of these two contaminants in the sludge management area (SMA). Second, it estimates the rate of soil erosion from the sludge management area relative to the corresponding rate for the entire drainage basin in which the SMA is located. It then combines these results to yield estimates of TCDD and TCDF concentrations in stream or lake sediments. Third, it uses estimated sediment concentrations to estimate contaminant concentrations in fish tissue and surface water.

Estimating Soil Concentrations in Sludge Management Areas

As discussed in the landfill and surface impoundments chapters (Chapters 2.2 and 2.3), the soil concentration of landfills and surface impoundments is assumed to equal the contaminant concentrations in the sludge. The methodology for calculating soil concentration for land application sites is explained in Appendix A.

Estimating Sediment Concentrations of TCDD and TCDF

Sediment concentrations are estimated from SMA soil concentrations by a method adapted from U.S. EPA (1985). In general, the method estimates sediment concentrations by adjusting concentrations in soil eroded from the SMA to account for mixing with soil eroded from the remainder of the stream or lake's drainage area. There are three groups of inputs to this calculation: the land areas of the SMA and the drainage basin, the soil loss parameters from the Universal Soil Loss Equation, and the sediment delivery ratios for the SMA and the drainage basin.

Quantities of soil eroding from both the sludge management area and the entire drainage basin are calculated with the Universal Soil Loss Equation (USLE), a simple mathematical model developed by the U.S. Department of Agriculture (Science and Education Administration and United States Department of Agriculture, December, 1978):

$$L_A = R\,K\,L\,S\,C\,P \qquad \text{(B.1)}$$

where:

L_A = rate of soil loss per unit area (tons/acre/year),

R = the rainfall and runoff factor, equals the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied water where such runoff is significant (years^{-1}),

K = the soil erodibility factor, equals the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft. length of uniform 9-percent slope continuously in clean-tilled fallow (tons/acre),

L = the slope length factor, equals the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions (unitless),

S = the slope-steepness factor, equals the ratio of soil loss from the field slope gradient to that from a 9-percent slope under otherwise identical conditions (unitless),

C = the cover and management factor, equals the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow (unitless),

P = the support practice factor, equals the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to that with straight-row farming up and down slope (unitless).

Results from the USLE equation are multiplied by estimated "sediment delivery ratios" to calculate the expected quantity of soil from the SMA and the drainage basin that reaches the water body. The sediment delivery ratio for the SMA estimates the reduction in soil mass delivered to a water body as the distance from the site to the river becomes larger (i.e. losses due to redeposition between the SMA and the river). An equation for estimating the sediment delivery ratio from the sludge management area is taken from U.S. EPA (1988c), and calculates the ratio as:

$$D_S = 0.77 \times (D_d)^{-0.22}$$

where:

D_S = sediment delivery ratio for the sludge management area (dimensionless),

D_d = the overland distance between the site and the receiving water body (meters).

The sediment delivery ratio for the total drainage area estimates the percent of sediment delivered to a specified downslope location in a drainage area. Based on three separate field investigations, Vanoni (1975) suggests that the relationship of sediment yield to drainage area can be approximated by:

$$D_B = 87.2A^{-.125}$$

where:

D_B = Sediment delivery ratio for the drainage area (unitless), and

A = Drainage area (hectares).

The sediment delivery ratio for the basin reflects the percentage of sediment delivered from the basin to any specified downslope location. This percentage is "affected by such factors as size and texture of erodible material, climate, land use, local environment, and general physiographic position" (Vanoni, 1975). There is no one relationship which represents sediment delivery ratios for every area. Even in one area, delivery ratios can vary substantially. For example, field investigations in the southeast Piedmont region of the United States found delivery ratios from 3.7 percent to 59.4 percent (Roehl, 1962 as cited in Vanoni, 1975). However, a decrease in delivery ratios with increasing drainage area is typical of most studies.

The watershed sediment delivery ratio is dependant on the area of the watershed. Ideally, drainage areas (or another "size" of stream estimate) would be available for each site. Unfortunately, obtaining site-specific data requires knowlege of the exact location of each SMA; exact locations were not available for this analysis. Since specific site locations are not known, it is impossible to determine whether each site's runoff flows directly into a major stream or, alternatively, into a relatively small tributary of the stream.

Generally, the large streams on which the mills are located have drainage areas of several thousand square miles (based on data from U.S. EPA's Graphical Exposure Modeling System). For this analysis, the SMA runoff is assumed to run directly into a major stream with a 5,000 square mile drainage area. Compared to the alternative of assuming the site empties into a relatively small tributary and that water and fish are consumed at the point of runoff entry, this assumption will yield low concentration estimates. However, compared to the assumption that the site empties into a relatively small tributary and is then transported to the main stream where water and fish are consumed, the concentrations will be high. Most sites are likely to be located near mills, in order to minimize sludge transportation costs. Since the mills are located on major streams, many of the sites may also be located near major streams. For a more refined analysis of the size of the receiving water body, site-specific locational and topographical information is needed. To incorporate the uncertainty in watershed size, the "low risk" estimate assumes a watershed area one tenth the size of the watershed in the "best" and "high estimates". Though the assumption of a smaller watershed results in higher estimate of water and fish concentration, it also leads to the assumption of a smaller exposed population. The net result is a decrease in the population risk estimate. The drainage area in the MEI scenarios is assumed to be approximately 40 square miles, which corresponds to a relatively small stream.

Given estimates of: (1) the total quantity of soil eroded from the SMA and the drainage basin, (2) the SMA and the drainage basin sediment delivery ratios, (3) the land area of the SMA and the drainage basin, and (4) the soil concentration, one can estimate the concentrations of contaminants in sediment as follows:

$$C_{SED} = \frac{C_S\, L_S\, A_S\, D_S}{A_B\, L_B\, D_B} \qquad (B.2)$$

where:

C_{SED} = Sediment concentrations of TCDD or TCDF (mg/kg)

C_S = Contaminant concentration in soil at the source, defined as the sludge management area (mg/kg)

L_S = Estimated soil loss for the SMA, calculated with the Universal Soil Loss Equation (tons/acre/year)

A_S = Source area (acres)

D_S = Sediment delivery ratio for the area between the source and the point of interest (dimensionless)

L_B = Estimated soil loss for the watershed upstream of the point of interest, calculated with the Universal Soil Loss Equation (tons/acre/year)

A_B = Watershed area upstream of the point of interest (acres)

D_B = Sediment delivery ratio for the watershed area upstream of the point of interest (dimensionless)

For some sludge management areas, most notably land application sites, the area treated with sludge may represent a significant fraction of the total drainage basin for the surface water body of concern. For these scenarios, Equation B.2 can be improved by splitting the denominator into two separate terms, where the first describes erosion from the SMA and the second describes erosion from the remainder of the drainage basin:

$$C_{SED} = \frac{C_S\, L_S\, A_S\, D_S}{[A_S\, L_S\, D_S] + [(A_B - A_S) L_B\, D_B]} \qquad \text{(B.3)}$$

This method of calculating sediment concentrations of TCDD and TCDF adjusts contaminant concentrations in sediment received from the SMA to account for mixing with uncontaminated sediments from the remainder of the drainage area. An alternative method is to determine the total quantity of adsorbed sludge contaminant received by the surface water body, and then to dilute this quantity by stream flow. Both methods require an estimate of the size of the water body, expressed either as the size of its drainage area, or as a volume of its water or water flow. The two methods yield similar concentration estimates (see Appendix C for a comparison of the two methods).

If characteristics of the sludge management area are the same as those of the entire drainage basin, then value of L_s used in Equation B.1 will be the same as the value of L_B, and these two variables can be dropped from Equations B.2 and B.3. This analysis assumes that R (the rainfall and runoff factor) and K (the soil erodibility factor) will be the same for both land areas. In addition, since topographical characteristics of the SMA's and the drainage basins are unavailable, it is assumed that the slope factors in the USLE equation (L and S) are equal for the basin and the drainage area. These four factors therefore cancel when substituted into Equation B.3, and inputs values need not be determined. The two remaining USLE parameters (cover and management factor, and support practice factor) are assumed to differ between the SMA and the remainder of the drainage basin for agricultural application, however, and cannot be ignored. Values assumed in the analysis are given in the relevant chapters.

Estimating TCDD and TCDF Concentrations in Surface Water and Fish Tissue

TCDD and TCDF adsorbed to sediments can reach humans if they are dissolved in surface water that is withdrawn for drinking water supplies, or if they concentrate in fish tissue that is then consumed by humans. Contaminant concentrations in each of these two media must be derived from estimated concentrations in sediment. Methods for these derivations will now be described.

Some of the adsorbed contaminant entering a surface water body will desorb from sludge or soil particles and dissolve into the water. At equilibrium, the relationship between concentrations of dissolved and adsorbed phases of contaminants in the water body is typically described by a partition coefficient (K_D), such that $K_D = C_S/C_L$, where C_S is the concentration of the contaminant adsorbed to solids (in g/g), and C_L is the concentration of contaminant dissolved in water (in g/cm^3). K_D was estimated by multiplying each contaminant's organic carbon partition coefficient (K_{OC}), by the fraction of organic carbon in the sediment. The Koc values used in this analysis were 0.04, 0.01, and 0.001 in the "low", "best", and "high" risk estimate, respectively.

K_d is used, along with assumptions about the relative quantities of sediment and water in the receiving water body, to estimate contaminant concentrations in adsorbed and dissolved phases. Sediment and water concentrations are calculated from "dry weight" sediment concentrations (calculated in Equation B.3) based on the following definitions:

$$K_D = \frac{M_{CS}/M_S}{M_{CW}/M_W} = \frac{M_{CS}\,M_W}{M_S\,M_{CW}}$$

$$C_{DW} = \frac{M_{CS}+M_{CW}}{M_S}$$

$$C_W = \frac{M_{CW}}{M_W}$$

$$P_S = \frac{M_S}{M_S+M_W}$$

$$P_L = 1-P_S$$

where:

K_D = partition coefficient between water and soil (cm^3/g),

M_{CS} = mass of contaminant in adsorbed to sediment (g),

M_W = mass of water (g),

M_S = mass of sediment (g),

M_{CW} = mass of contaminant dissolved in water (g),

C_{DW} = dry weight concentration of contaminant in sediment (g/g),

C_W = dissolved concentration of contaminant in water (mg/kg),

P_S = percent solids in water body (unitless),

P_L = percent liquid in water body (unitless),

C_s = contaminant concentration in sediment (mg/kg),

From these equations it follows that:

$$C_w = \frac{C_{dw}}{(K_d + P_L/P_S)}$$

Since $K_d = C_s/C_w$, C_s can be calculated from C_w by:

$$C_s = C_w \times K_d$$

In order to estimate the sediment and water concentrations, an estimate must be made of the percent of the mass in contact with the contaminant that is solid. Although the mass of suspended solids can be estimated for a given stream, the mass of the bottom sediment is not as easily determined. For lack of more detailed information, this analysis assumes that the mass of sediment (M_S) equals the mass of water (M_W), so that P_L/P_S is equal to one. If the mass of water is actually greater than the mass of solids, the current calculation will over estimate water concentrations and under estimate sediment concentrations. However, due to the large K_d values of TCDD and TCDF, the effect of the relative mass of solids and liquids on contaminant concentrations is negligible.

Without specific site runoff information and waterway characteristics, it is impossible to calculate dispersion and further dilution as a consequence of transport by the waterway. This analysis therefore uses each contaminant's concentration at the "point" of runoff entry to estimate water and fish concentrations for all populations exposed through water ingestion and fish consumption. Actual exposure is likely to be lower in most cases, as a result of dispersion and dilution.

Fish to Sediment Bioconcentration Factors

This analysis estimates bioaccumulation in fish as a function of a fish to sediment bioconcentration factor (BCF). According to an EPA (1989b), "Bioconcentration factors based on sediment exposure are probably more realistic than those based on water concentrations because of the strong potential for tetrachlorodibenzodioxin to partition to suspended solids and sediments in the aquatic environment."

This analysis assumes that the fish and sediment are at "steady-state" and that the levels of TCDD and TCDF in the sediment remain essentially constant at a particular location over time. Separate bioconcentration factors are used for TCDD and TCDF. Although a single bioconcentration factor is used for all species, they will probably vary for different species, with higher bioconcentration factor's associated with bottom-feeders and fish with high lipid percentages. In addition, time to reach steady-state will likely vary, with some species never reaching a steady state concentration.

Contaminant concentrations in fish tissue are related to sediment concentrations by:

$$C_{FW} = C_S \, BCF$$

where:

C_{FW} = concentration of contaminant in whole fish (mg/kg)

C_S = concentration of contaminant in sediment (mg/kg)

BCF = fish to sediment bioconcentration factor (unitless)

Since fish to sediment bioconcentration factors are usually reported on the basis of whole body tissue concentrations, these estimates are adjusted to reflect the concentration of contaminant in the muscle, or filet, of the fish. Concentration in filet is estimated to be 50 percent of the whole body concentrations (EPA, 1989b), so estimated concentrations are adjusted by 0.5:

$$C_F = 0.5 \, C_S \, BCF$$

where:

C_F = concentration of contaminant in fish fillet (mg/kg).

U.S. EPA (1988b) reviewed a variety of studies on fish to sediment bioconcentration factors, and observed that the ratios typically range from 1:1 to 10:1. This range may reflect variability resulting from a number of interdependent factors including species, lipid content, weight, ratio of surface area to weight, organic carbon content of the sediment, food intake rate, density of suspended particulate matter, and concentration of 2,3,7,8-TCDD in the sediment. For exposure calculations, U.S. EPA (1988b) used a single value of 5:1 for the fish to sediment concentration ratio.

More recent data from EPA (1989b) reports on seven measurements of bioconcentration factors from sediment exposures. The mean fish bioconcentration factor for 2,3,7,8-TCDD from contaminated sediments is reported as 0.0967 for the seven studies (whole body, wet weight basis). This factor is stated to be most reliable for sediment concentrations from 39.0 ppt to 2000.0 ppt. This analysis uses 0.0967 for the whole body bioconcentration factor in the "low" and "best" estimates and 5 for the "high" estimate.

Only one study measured the fish to sediment ratio for 2,3,7,8-TCDF (U.S. EPA, 1989b). In this study a warm water species exposed to sediment concentration at 182 ppt of TCDF, had a bioconcentration factor of 0.1538 on a whole body, wet weight basis. This analysis uses 0.1538 for the bioconcentration factor in the "low" and "best" estimates and 5 for the "high" estimate.

References

U.S. EPA (1985). TCDD Transport from Contaminated Sites to Exposed URE Locations: A Methodology for Calculating Conversion Factors. Final Report. G.W. Dawson, et al. Battell project management division. Richland, WA. June.

U.S. EPA (1988a). Development of a Method for Estimating Exposure from the Disposal of Chemical Substances in Landfills. Office of Toxic Substances, Exposure Evaluation Division, Exposure Assessment Branch. EPA Contract No. 68-02-4254. September.

U.S. EPA (1988b). Estimating Exposures to 2,3,7,8-TCDD. Office of Health and Environmental Assessment, EPA/600/6-88/005A. External Review Draft, March.

U.S. EPA (1988c). Development of Risk Assessment methodology for Land Application and Distribution and Marketing of Municipal Sludge. Prepared by Environmental Criteria and Assessment Office, Cincinnati, OH.

U.S. EPA (1989a). Graphical Exposure Modeling System User Guide. Office of Toxic Substances. March.

U.S. EPA (1989b). Memorandum: "OTS/EEB Aquatic Life Hazard Assessment (Including BCF Values) for 'Dioxins in Paper'". Office of Pesticides and Toxic Substances. Washington, D.C. August.

Vanoni, Vita A., Editor (1975). "Sedimentation Engineering." Prepared by the ASCE task committee for the preparation of the manual on sedimentation of the sedimentation committee of the hydraulics division. NY, NY.

Appendix C. Comparison of Two Methods for Estimating Sediment and Water Contaminant Concentrations Resulting from Contaminated Soil Erosion from Sludge Management Areas

Appendix B explained the method used in this analysis to estimate sediment and water contaminant concentrations resulting from contaminated soil erosion from sludge management areas. Concentrations are estimated by diluting the contaminated sediment from a SMA by the uncontaminated sediment received from the remainder of the drainage area. The contaminant is then partitioned between dissolved and sorbed phases to yield estimates of water concentration and sediment concentration.

An alternative method is to determine the total quantity of adsorbed sludge contaminant received by the surface water body and then to dilute this quantity by dividing by stream flow. As in the method used in this analysis, the contaminant would then be partitioned between dissolved and sorbed phases to yield water concentration and sediment concentration estimates.

To determine whether these methods yield similar results, this appendix calculates the final water contaminant concentration from soil erosion from a sludge surface impoundment by the second method and compares the result to the method used in the text of this report. The method used in this report (described in Appendix B) results in a TCDD water concentration after partitioning of 4.3×10^{-16} mg/kg for a surface impoundment with the characteristics described in Table 2.3.G for the "best estimate".

The alternate calculation consists of two steps. First a loading of contaminant to the water body is determined and the contaminant is diluted by stream flow. Second, the contaminant is partitioned between water and sediment. The calculation to determine the water concentration before partitioning is:

$$CB = \frac{WL \times C \times A}{SF}$$

where

CB = Concentration in the stream before partitioning (mg/kg);
WL = Washload from the SMA to the stream (kgs/day/acre);
C = Concentration of contaminant sorbed to the eroded soil (mg/kg);
A = Area of the SMA (acres);
SF = Stream flow (liters/day).

A washload is calculated from the soil erosion rate using the Nationwide Cropland Soil Erosion Statistics (USDA 1982). The erosion rate is determined by dividing total erosion by total acreage as given by USDA. As a "best estimate" the amount of erosion and associated acreage reported at the 50th percent are used to calculate washload. The 50th percentile calculated washload is 3.7 kg/acre/day.

The area of a surface impoundment used in the "best estimate" is 73.5 acres. The concentration of contaminant sorbed to the eroded soil is assumed to be 1 mg/kg. Stream flow measurements for all streams receiving effluent directly or indirectly from POTWs are used to estimate dilution. These stream are assumed to be representative of streams receiving industrial effluent. Two stream flow rates are used to estimate dilution: the 10th percentile low flow rate and the 50th percentile mean flow rate. Flow rates are 0.53 million liters per day and 478 million liters per day, respectively (U.S. EPA, 1988).

Using these input values, the concentration in water before partitioning is:

Low flow rate:

$$\frac{3.7\ \text{kg/acre/day} \times 73.5\ \text{acres} \times 1\ \text{mg/kg}}{0\ .53 \times 10^{6}\ \text{liters/day}} = 5.1 \times 10^{-10}\ \text{mg/kg}$$

Mean flow rate:

$$\frac{3.7\ \text{kg/acre/day} \times 73.5\ \text{acres} \times 1\ \text{ppm}}{478 \times 10^{6}\ \text{liters/day}} = 5.7 \times 10^{-13}\ \text{mg/kg}$$

The partition coefficient, Kd, describes the relationship between concentrations of dissolved and sorbed phases of contaminant at equilibrium. The Kd used in this analysis for TCDD is 1×10^{5}. Water concentrations are calculated by:

$$CA = CB \times 1/(1 + Kd)$$

where:

CA = Concentration in water after partitioning (mg/kg);
CB = Concentration in water before partitioning (mg/kg);
Kd = Partition coefficient (cm^{3}/g).

Substituting the water concentration before partitioning into the partitioning equation, yields a concentration in water of 5.1×10^{-15} mg/kg using the low stream flow, and 5.7×10^{-18} mg/kg using the high stream flow. These values compare well with the estimate of TCDD concentration in water derived using the method described in Appendix B.

References

U.S. Department of Agriculture (1982). National Cropland Soil Erosion Statistics. In: A National Program for Soil and Water Conservation (1982). Final Program Report and Environmental Impact Statement. Soil Conservation Service. Washington, D.C.

U.S. EPA (1988). Industry Facilities Discharge file. Retrievals from the Hydrologically Linked Data File System. Washington, D.C.

Versar (1988). PCB Exposure Assessment of Scrap Salvage Facilities. Revised draft report. September.

Appendix D.1. Wildlife Risks: "Low Risk" Scenario

Table D.1.A. Low Estimate of Exposure and Risk to Georgia Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	7.3E+00	2.0E+01	8.8E+01	4.2E+01	67%	18%	136%	6%
Flycatcher	6.2E+00	1.7E+01	5.5E+01	2.6E+01	56%	16%	85%	4%
Swallow	6.3E+00	1.7E+01	7.3E+01	3.5E+01	57%	16%	112%	5%
Warbler	9.0E+00	2.5E+01	6.0E+01	2.9E+01	82%	23%	92%	4%
Woodcock	7.4E+00	2.1E+01	8.9E+01	4.2E+01	68%	19%	136%	7%
Woodthrush	3.7E+00	1.0E+01	3.6E+01	1.7E+01	33%	9%	55%	3%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.B. Low Estimate of Exposure and Risk to Maryland Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	3.2E+00	1.9E+01	1.8E+01	1.8E+01	29%	17%	27%	3%
Robin	3.2E+00	1.9E+01	3.9E+01	4.0E+01	30%	17%	60%	6%
Flycatcher	2.7E+00	1.6E+01	2.4E+01	2.5E+01	25%	15%	38%	4%
Shrike	4.2E+00	2.5E+01	5.8E+01	4.3E+01	70%	41%	90%	7%
Meadowlark	1.7E+00	1.0E+01	1.9E+01	1.9E+01	15%	9%	29%	3%
Swallow	2.8E+00	1.6E+01	3.2E+01	3.2E+01	25%	15%	49%	5%
Warbler	4.0E+00	2.3E+01	2.7E+01	2.7E+01	36%	21%	41%	4%
Woodcock	3.3E+00	1.9E+01	3.9E+01	4.0E+01	30%	18%	60%	6%
Woodthrush	1.6E+00	9.5E+00	1.6E+01	1.6E+01	15%	9%	24%	2%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.
2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.
3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.C. Low Estimate of Exposure and Risk to Ohio Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	5.8E+00	3.2E+01	3.2E+01	3.0E+01	53%	29%	49%	5%
Robin	5.9E+00	3.2E+01	7.1E+01	6.7E+01	53%	29%	109%	10%
Flycatcher	5.0E+00	2.7E+01	4.4E+01	4.2E+01	45%	25%	68%	6%
Shrike	7.7E+00	4.2E+01	1.1E+02	7.3E+01	128%	70%	163%	11%
Meadowlark	3.1E+00	1.7E+01	3.5E+01	3.3E+01	28%	15%	53%	5%
Swallow	5.0E+00	2.8E+01	5.8E+01	5.5E+01	46%	25%	89%	8%
Warbler	7.2E+00	3.9E+01	4.8E+01	4.5E+01	65%	36%	74%	7%
Woodthrush	2.9E+00	1.6E+01	2.9E+01	2.7E+01	27%	15%	44%	4%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.D. Low Estimate of Exposure and Risk to Pennsylvania Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	9.2E-03	2.7E-03	5.0E-02	2.6E-03	0%	0%	0%	0%
Robin	9.3E-03	2.8E-03	1.1E-01	5.7E-03	0%	0%	0%	0%
Flycatcher	7.8E-03	2.3E-03	7.0E-02	3.6E-03	0%	0%	0%	0%
Shrike	1.2E-02	3.6E-03	1.7E-01	6.2E-03	0%	0%	0%	0%
Meadowlark	4.8E-03	1.4E-03	5.4E-02	2.8E-03	0%	0%	0%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.E. Low Estimate of Exposure and Risk to Maine Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	4.0E-02	2.0E-01	2.2E-01	1.9E-01	0%	0%	0%	0%
Robin	4.1E-02	2.0E-01	4.9E-01	4.2E-01	0%	0%	1%	0%
Swallow	3.5E-02	1.7E-01	4.0E-01	3.4E-01	0%	0%	1%	0%
Warbler	5.0E-02	2.5E-01	3.3E-01	2.9E-01	0%	0%	1%	0%
Woodcock	4.1E-02	2.1E-01	4.9E-01	4.2E-01	0%	0%	1%	0%
Woodthrush	2.0E-02	1.0E-01	2.0E-01	1.7E-01	0%	0%	0%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.F. Low Estimate of Exposure and Risk to Wisconsin Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	3.6E-01	4.3E+00	2.0E+00	4.0E+00	3%	4%	3%	1%
Robin	3.7E-01	4.3E+00	4.4E+00	8.9E+00	3%	4%	7%	1%
Swallow	3.1E-01	3.7E+00	3.6E+00	7.3E+00	3%	3%	6%	1%
Warbler	4.5E-01	5.3E+00	3.0E+00	6.1E+00	4%	5%	5%	1%
Woodcock	3.7E-01	4.4E+00	4.4E+00	8.9E+00	3%	4%	7%	1%
Woodthrush	1.8E-01	2.1E+00	1.8E+00	3.6E+00	2%	2%	3%	1%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.G. Low Estimate of Exposure and Risk to Mississippi Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	5.8E-01	0.0E+00	7.0E+00	0.0E+00	5%	0%	11%	0%
Flycatcher	4.9E-01	0.0E+00	4.4E+00	0.0E+00	4%	0%	7%	0%
Shrike	7.5E-01	0.0E+00	1.0E+01	0.0E+00	13%	0%	16%	0%
Meadowlark	3.0E-01	0.0E+00	3.4E+00	0.0E+00	3%	0%	5%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.
2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.
3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.1.H. Low Estimate of Exposure and Risk to Georgia Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	3.6E+01	1.0E+02	6.3E+00	2.2E+00	362%	100%
Mole	1.2E+01	3.4E+01	1.3E+01	4.6E+00	122%	34%
Otter	1.2E-04	3.2E-04	4.5E-02	1.6E-02	0%	0%
Opossum	1.2E+00	3.4E+00	1.9E+02	6.5E+01	72%	20%
Shrew	3.0E+01	8.3E+01	3.2E+00	1.1E+00	299%	83%
Skunk	6.5E-01	1.8E+00	6.5E+01	2.2E+01	38%	11%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.1.1. Low Estimate of Exposure and Risk to Maryland Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	1.6E+01	9.4E+01	2.8E+00	2.0E+00	160%	94%
Mole	5.4E+00	3.2E+01	5.8E+00	4.3E+00	54%	32%
Otter	5.2E-05	3.0E-04	2.0E-02	1.5E-02	0%	0%
Opossum	5.4E-01	3.2E+00	8.2E+01	6.1E+01	32%	19%
Shrew	1.3E+01	7.8E+01	1.4E+00	1.1E+00	132%	78%
Skunk	2.9E-01	1.7E+00	2.9E+01	2.1E+01	17%	10%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.1.J. Low Estimate of Exposure and Risk to Ohio Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	2.9E+01	1.6E+02	5.0E+00	3.4E+00	290%	159%
Mole	9.8E+00	5.4E+01	1.1E+01	7.3E+00	98%	54%
Otter	9.3E-05	5.1E-04	3.6E-02	2.5E-02	0%	0%
Opossum	9.9E-01	5.4E+00	1.5E+02	1.0E+02	58%	32%
Shrew	2.4E+01	1.3E+02	2.6E+00	1.8E+00	239%	131%
Skunk	5.2E-01	2.9E+00	5.2E+01	3.6E+01	31%	17%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles. and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.1.K. Low Estimate of Exposure and Risk to Maine Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	2.0E-01	1.0E+00	3.5E-02	2.2E-02	2%	1%
Mole	6.7E-02	3.4E-01	7.3E-02	4.6E-02	1%	0%
Otter	6.4E-07	3.2E-06	2.5E-04	1.6E-04	0%	0%
Opossum	6.8E-03	3.4E-02	1.0E+00	6.4E-01	0%	0%
Shrew	1.7E-01	8.3E-01	1.8E-02	1.1E-02	2%	1%
Skunk	3.6E-03	1.8E-02	3.6E-01	2.2E-01	0%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.1.L. Low Estimate of Exposure and Risk to Wisconsin Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	1.8E+00	2.1E+01	3.1E-01	4.6E-01	18%	21%
Mole	6.1E-01	7.1E+00	6.6E-01	9.7E-01	6%	7%
Otter	5.8E-06	6.8E-05	2.3E-03	3.3E-03	0%	0%
Opossum	6.1E-02	7.2E-01	9.3E+00	1.4E+01	4%	4%
Shrew	1.5E+00	1.7E+01	1.6E-01	2.4E-01	15%	17%
Skunk	3.2E-02	3.8E-01	3.2E+00	4.8E+00	2%	2%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.1.M. Low Estimate of Exposure and Risk to Mississippi Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body bu:den of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Armadillo	1.8E-01	0.0E+00	3.1E+01	0.0E+00	11%	0%
Bat	2.9E+00	0.0E+00	5.0E-01	0.0E+00	29%	0%
Mole	9.6E-01	0.0E+00	1.0E+00	0.0E+00	10%	0%
Otter	9.2E-06	0.0E+00	3.6E-03	0.0E+00	0%	0%
Opossum	9.7E-02	0.0E+00	1.5E+01	0.0E+00	6%	0%
Shrew	2.4E+00	0.0E+00	2.6E-01	0.0E+00	24%	0%
Skunk	5.2E-02	0.0E+00	5.1E+00	0.0E+00	3%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for armadillo, otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for armadillo, otter, opossum, and skunk.

Table D.1.N. Low Estimate of Exposure and Risk to Pennsylvania Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to the LOAEL for TCDD (percent)	Comparison to the LOAEL for TCDF (percent)
Bat	4.6E-02	1.4E-02	7.9E-03	3.0E-04	0%	0%
Mole	1.5E-02	4.6E-03	1.7E-02	6.2E-04	0%	0%
Otter	1.5E-07	4.4E-08	5.7E-05	2.1E-06	0%	0%
Opossum	1.6E-03	4.6E-04	2.3E-01	8.8E-03	0%	0%
Shrew	3.8E-02	1.1E-02	4.1E-03	1.5E-04	0%	0%
Skunk	8.2E-04	2.5E-04	8.2E-02	3.1E-03	0%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bats, moles, and shrews; comparison to LOAEL of 1.7 ng/kg/day TCDD for otter, opossum and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bats, moles, and shrews; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Appendix D.2. Wildlife Risks: "Best Estimate" Scenario

Table D.2.A. Best Estimate of Exposure and Risk to Georgia Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	4.5E+01	1.3E+02	6.9E+02	2.8E+02	413%	114%	1059%	44%
Flycatcher	3.6E+01	1.0E+02	4.1E+02	1.7E+02	328%	91%	624%	26%
Tree swallow	3.7E+01	1.0E+02	5.3E+02	2.2E+02	334%	92%	818%	34%
Pine warbler	5.2E+01	1.4E+02	4.4E+02	1.8E+02	476%	132%	679%	28%
Woodcock	3.0E+02	8.4E+02	4.1E+03	1.9E+03	2761%	764%	6237%	288%
Woodthrush	2.1E+01	5.9E+01	2.6E+02	1.1E+02	194%	54%	405%	17%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.B. Best Estimate of Exposure and Risk to Maryland Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	1.9E+01	1.1E+02	2.4E+02	2.1E+02	170%	100%	372%	33%
Robin	2.0E+01	1.2E+02	3.0E+02	2.7E+02	183%	107%	468%	41%
Flycatcher	1.6E+01	9.4E+01	1.8E+02	1.6E+02	145%	85%	276%	24%
Shrike	1.7E+01	1.0E+02	2.6E+02	1.9E+02	287%	169%	397%	29%
Meadowlark	9.7E+00	5.7E+01	1.4E+02	1.2E+02	88%	52%	211%	18%
Swallow	1.6E+01	9.6E+01	2.4E+02	2.1E+02	147%	87%	362%	32%
Warbler	2.3E+01	1.4E+02	1.9E+02	1.7E+02	210%	124%	300%	26%
Woodcock	1.3E+02	7.9E+02	1.8E+03	1.8E+03	1220%	719%	2757%	270%
Woodthrush	9.4E+00	5.5E+01	1.2E+02	1.0E+02	86%	50%	179%	16%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.C. Best Estimate of Exposure and Risk to Ohio Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	3.4E+01	1.9E+02	4.4E+02	3.6E+02	309%	169%	675%	55%
Robin	3.6E+01	2.0E+02	5.5E+02	4.5E+02	331%	181%	849%	69%
Flycatcher	2.9E+01	1.6E+02	3.2E+02	2.6E+02	263%	144%	500%	41%
Shrike	3.1E+01	1.7E+02	4.7E+02	3.2E+02	520%	285%	720%	49%
Meadowlark	1.8E+01	9.6E+01	2.5E+02	2.0E+02	160%	88%	382%	31%
Swallow	2.9E+01	1.6E+02	4.3E+02	3.5E+02	267%	147%	655%	53%
Warbler	4.2E+01	2.3E+02	3.5E+02	2.9E+02	381%	209%	544%	44%
Woodthrush	1.7E+01	9.4E+01	2.1E+02	1.7E+02	155%	85%	325%	26%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.
2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.
3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.D. Best Estimate of Exposure and Risk to Pennsylvania Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	5.3E-02	1.6E-02	6.9E-01	3.1E-02	0%	0%	1%	0%
Robin	5.7E-02	1.7E-02	8.7E-01	3.8E-02	1%	0%	1%	0%
Flycatcher	4.5E-02	1.4E-02	5.1E-01	2.3E-02	0%	0%	1%	0%
Shrike	4.9E-02	1.5E-02	7.4E-01	2.8E-02	1%	0%	1%	0%
Meadowlark	2.8E-02	8.3E-03	3.9E-01	1.7E-02	0%	0%	1%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.
2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.
3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.E. Best Estimate of Exposure and Risk to Maine Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	2.3E-01	1.2E+00	3.0E+00	2.2E+00	2%	1%	5%	0%
Robin	2.5E-01	1.3E+00	3.8E+00	2.8E+00	2%	1%	6%	0%
Swallow	2.0E-01	1.0E+00	2.9E+00	2.2E+00	2%	1%	5%	0%
Warbler	2.9E-01	1.4E+00	2.4E+00	1.8E+00	3%	1%	4%	0%
Woodcock	1.7E+00	8.4E+00	2.2E+01	1.9E+01	15%	8%	34%	3%
Woodthrush	1.2E-01	5.9E-01	1.5E+00	1.1E+00	1%	1%	2%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.F. Best Estimate of Exposure and Risk to Wisconsin Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	2.1E+00	2.5E+01	2.7E+01	4.8E+01	19%	23%	42%	7%
Robin	2.3E+00	2.7E+01	3.4E+01	6.0E+01	21%	24%	53%	9%
Swallow	1.8E+00	2.1E+01	2.6E+01	4.6E+01	17%	20%	41%	7%
Warbler	2.6E+00	3.1E+01	2.2E+01	3.8E+01	24%	28%	34%	6%
Woodcock	1.5E+01	1.8E+02	2.0E+02	4.0E+02	137%	162%	310%	61%
Woodthrush	1.1E+00	1.2E+01	1.3E+01	2.3E+01	10%	11%	20%	4%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.G. Best Estimate of Exposure and Risk to Mississippi Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	3.6E+00	0.0E+00	5.4E+01	0.0E+00	33%	0%	84%	0%
Flycatcher	2.8E+00	0.0E+00	3.2E+01	0.0E+00	26%	0%	49%	0%
Shrike	3.1E+00	0.0E+00	4.6E+01	0.0E+00	51%	0%	71%	0%
Meadowlark	1.7E+00	0.0E+00	2.4E+01	0.0E+00	16%	0%	38%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.2.H. Best Estimate of Exposure and Risk to Georgia Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.8E+02	5.0E+02	6.3E+01	2.2E+01	1810%	501%
Mole	1.5E+02	4.3E+02	3.3E+02	1.2E+02	1540%	426%
Otter	1.9E-03	5.4E-03	1.5E+00	5.2E-01	0%	0%
Opossum	4.9E+00	1.4E+01	1.5E+03	5.1E+02	288%	80%
Shrew	4.5E+02	1.2E+03	1.0E+02	3.5E+01	4480%	1240%
Skunk	3.3E+00	9.0E+00	6.5E+02	2.2E+02	192%	53%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.2.1. Best Estimate of Exposure and Risk to Maryland Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	8.0E+01	4.7E+02	2.8E+01	2.0E+01	800%	471%
Mole	6.8E+01	4.0E+02	1.5E+02	1.1E+02	681%	401%
Otter	8.6E-04	5.1E-03	6.7E-01	4.9E-01	0%	0%
Opossum	2.2E+00	1.3E+01	6.6E+02	4.8E+02	127%	75%
Shrew	2.0E+02	1.2E+03	4.4E+01	3.3E+01	1980%	1166%
Skunk	1.4E+00	8.5E+00	2.9E+02	2.1E+02	85%	50%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.2.J. Best Estimate of Exposure and Risk to Ohio Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.5E+02	8.0E+02	5.0E+01	3.4E+01	1450%	795%
Mole	1.2E+02	6.8E+02	2.7E+02	1.8E+02	1234%	676%
Otter	1.6E-03	8.5E-03	1.2E+00	8.3E-01	0%	0%
Opossum	3.9E+00	2.2E+01	1.2E+03	8.1E+02	231%	127%
Shrew	3.6E+02	2.0E+03	8.0E+01	5.5E+01	3589%	1968%
Skunk	2.6E+00	1.4E+01	5.2E+02	3.6E+02	154%	84%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.2.K. Best Estimate of Exposure and Risk to Maine Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.0E+00	5.0E+00	3.5E-01	2.2E-01	10%	5%
Mole	8.5E-01	4.3E+00	1.8E+00	1.2E+00	9%	4%
Otter	1.1E-05	5.4E-05	8.4E-03	5.2E-03	0%	0%
Opossum	2.7E-02	1.4E-01	8.2E+00	5.1E+00	2%	1%
Shrew	2.5E+00	1.2E+01	5.5E-01	3.5E-01	25%	12%
Skunk	1.8E-02	9.0E-02	3.6E+00	2.2E+00	1%	1%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.2.L. Best Estimate of Exposure and Risk to Wisconsin Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	9.0E+00	1.1E+02	3.1E+00	4.6E+00	90%	106%
Mole	7.7E+00	9.0E+01	1.7E+01	2.4E+01	77%	90%
Otter	9.7E-05	1.1E-03	7.5E-02	1.1E-01	0%	0%
Opossum	2.4E-01	2.9E+00	7.4E+01	1.1E+02	14%	17%
Shrew	2.2E+01	2.6E+02	5.0E+00	7.3E+00	223%	262%
Skunk	1.6E-01	1.9E+00	3.2E+01	4.8E+01	10%	11%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.2.M. Best Estimate of Exposure and Risk to Mississippi Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Armadillo	5.3E-01	0.0E+00	1.8E+02	0.0E+00	31%	0%
Bat	1.4E+01	0.0E+00	5.0E+00	0.0E+00	143%	0%
Mole	1.2E+01	0.0E+00	2.6E+01	0.0E+00	122%	0%
Otter	1.5E-04	0.0E+00	1.2E-01	0.0E+00	0%	0%
Opossum	3.9E-01	0.0E+00	1.2E+02	0.0E+00	23%	0%
Shrew	3.5E+01	0.0E+00	7.9E+00	0.0E+00	354%	0%
Skunk	2.6E-01	0.0E+00	5.1E+01	0.0E+00	15%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for armadillo, otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for armadillo, otter, opossum, and skunk.

Table D.2.N. Best Estimate of Exposure and Risk to Pennsylvania Mammals

Organism	Daily dose of TCDD (ng/kg/day)	Daily dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDD (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	2.3E-01	6.8E-02	7.9E-02	3.0E-03	2%	0%
Mole	1.9E-01	5.8E-02	4.2E-01	1.6E-02	2%	0%
Otter	2.4E-06	7.3E-07	1.9E-03	7.1E-05	0%	0%
Opossum	6.2E-03	1.8E-03	1.9E+00	7.0E-02	0%	0%
Shrew	5.6E-01	1.7E-01	1.3E-01	4.7E-03	6%	0%
Skunk	4.1E-03	1.2E-03	8.2E-01	3.1E-02	0%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison of 1.7 ng/kg/day TCDD for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Appendix D.3. Wildlife Risks: "High Risk" Scenario

Table D.3.A. High Estimate of Exposure and Risk to Georgia Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	7.2E+01	2.0E+02	2.0E+03	8.6E+02	657%	182%	3016%	132%
Flycatcher	5.4E+01	1.5E+02	1.1E+03	4.8E+02	493%	136%	1680%	73%
Tree swallow	5.6E+01	1.5E+02	1.4E+03	6.3E+02	505%	140%	2219%	97%
Pine warbler	7.9E+01	2.2E+02	1.2E+03	5.2E+02	715%	198%	1826%	80%
Woodcock	8.7E+02	2.4E+03	2.3E+04	1.0E+04	7889%	2184%	35832%	1567%
Woodthrush	3.3E+01	9.1E+01	7.2E+02	3.2E+02	298%	82%	1115%	49%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.B. High Estimate of Exposure and Risk to Maryland Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	2.9E+01	1.7E+02	6.6E+02	6.2E+02	261%	153%	1019%	95%
Robin	3.2E+01	1.9E+02	8.7E+02	8.1E+02	290%	171%	1333%	124%
Flycatcher	2.4E+01	1.4E+02	4.8E+02	4.5E+02	218%	128%	743%	69%
Shrike	2.3E+01	1.3E+02	5.1E+02	4.8E+02	378%	222%	788%	73%
Meadowlark	1.5E+01	8.6E+01	3.7E+02	3.5E+02	133%	79%	571%	53%
Swallow	2.5E+01	1.4E+02	6.4E+02	5.9E+02	223%	132%	981%	91%
Warbler	3.5E+01	2.0E+02	5.2E+02	4.9E+02	316%	186%	807%	75%
Woodcock	3.8E+02	2.3E+03	1.0E+04	9.6E+03	3487%	2053%	15837%	1474%
Woodthrush	1.4E+01	8.5E+01	3.2E+02	3.0E+02	132%	78%	493%	46%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.C. High Estimate of Exposure and Risk to Ohio Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	5.2E+01	2.8E+02	1.2E+03	1.0E+03	472%	259%	1847%	160%
Robin	5.8E+01	3.2E+02	1.6E+03	1.4E+03	526%	289%	2416%	209%
Flycatcher	4.3E+01	2.4E+02	8.7E+02	7.6E+02	395%	217%	1346%	117%
Shrike	4.1E+01	2.3E+02	9.3E+02	8.0E+02	685%	375%	1429%	124%
Meadowlark	2.7E+01	1.5E+02	6.7E+02	5.8E+02	242%	133%	1034%	90%
Swallow	4.5E+01	2.4E+02	1.2E+03	1.0E+03	405%	222%	1777%	154%
Warbler	6.3E+01	3.5E+02	9.5E+02	8.2E+02	573%	314%	1463%	127%
Woodthrush	2.6E+01	1.4E+02	5.8E+02	5.0E+02	239%	131%	893%	77%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.D. High Estimate of Exposure and Risk to Pennsylvania Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	8.2E-02	2.4E-02	1.9E+00	8.9E-02	1%	0%	3%	0%
Robin	9.1E-02	2.7E-02	2.5E+00	1.2E-01	1%	0%	4%	0%
Flycatcher	6.8E-02	2.0E-02	1.4E+00	6.5E-02	1%	0%	2%	0%
Shrike	6.5E-02	1.9E-02	1.5E+00	6.9E-02	1%	0%	2%	0%
Meadowlark	4.2E-02	1.3E-02	1.1E+00	5.0E-02	0%	0%	2%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.E. High Estimate of Exposure and Risk to Maine Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	3.6E-01	1.8E+00	8.3E+00	6.5E+00	3%	2%	13%	1%
Robin	4.0E-01	2.0E+00	1.1E+01	8.6E+00	4%	2%	17%	1%
Swallow	3.1E-01	1.5E+00	8.0E+00	6.3E+00	3%	1%	12%	1%
Warbler	4.3E-01	2.2E+00	6.6E+00	5.2E+00	4%	2%	10%	1%
Woodcock	4.8E+00	2.4E+01	1.3E+02	1.0E+02	44%	22%	198%	16%
Woodthrush	1.8E-01	9.1E-01	4.0E+00	3.2E+00	2%	1%	6%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.F. High Estimate of Exposure and Risk to Wisconsin Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Bluebird	3.2E+00	3.8E+01	7.4E+01	1.4E+02	29%	35%	115%	21%
Robin	3.6E+00	4.2E+01	9.7E+01	1.8E+02	33%	38%	150%	28%
Swallow	2.8E+00	3.3E+01	7.2E+01	1.3E+02	25%	30%	110%	21%
Warbler	3.9E+00	4.6E+01	5.9E+01	1.1E+02	36%	42%	91%	17%
Woodcock	4.3E+01	5.1E+02	1.2E+03	2.2E+03	392%	462%	1782%	332%
Woodthrush	1.6E+00	1.9E+01	3.6E+01	6.7E+01	15%	17%	55%	10%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.G. High Estimate of Exposure and Risk to Mississippi Birds

Organism	Daily dose TCDD (ng/kg/day)	Daily dose TCDF (ng/kg/day)	Egg concentration TCDD (ng/kg)	Egg concentration TCDF (ng/kg)	Comparison to NOAEL for adults TCDD (percent)	Comparison to NOAEL for adults TCDF (percent)	Comparison to LOAEL for embryo TCDD (percent)	Comparison to LOAEL for embryo TCDF (percent)
Robin	5.7E+00	0.0E+00	1.5E+02	0.0E+00	52%	0%	238%	0%
Flycatcher	4.3E+00	0.0E+00	8.6E+01	0.0E+00	39%	0%	133%	0%
Shrike	4.1E+00	0.0E+00	9.2E+01	0.0E+00	68%	0%	141%	0%
Meadowlark	2.6E+00	0.0E+00	6.6E+01	0.0E+00	24%	0%	102%	0%

1) TCDD NOAEL for migratory birds is 11 ng/kg/day; TCDF NOAEL is 110 ng/kg/day.

2) TCDD NOAEL for non-migratory birds is 6 ng/kg/day; TCDF NOAEL is 60 ng/kg/day.

3) TCDD LOAEL for embryos is 65 ng/kg/day; TCDF LOAEL is 650 ng/kg/day.

Table D.3.H. High Estimate of Exposure and Risk to Georgia Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	2.7E+02	7.5E+02	1.2E+02	4.0E+01	2715%	752%
Mole	3.9E+02	1.1E+03	1.0E+03	3.6E+02	3850%	1066%
Otter	1.0E-01	2.8E-01	4.8E+02	1.6E+02	6%	2%
Opossum	8.0E+00	2.2E+01	1.5E+04	5.1E+03	469%	130%
Shrew	1.1E+03	3.2E+03	3.1E+02	1.1E+02	11448%	3169%
Skunk	4.9E+00	1.4E+01	6.0E+03	2.1E+03	289%	80%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.3.1. High Estimate of Exposure and Risk to Maryland Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.2E+02	7.1E+02	5.1E+01	3.8E+01	1200%	707%
Mole	1.7E+02	1.0E+03	4.5E+02	3.3E+02	1702%	1002%
Otter	4.4E-02	2.6E-01	2.1E+02	1.6E+02	3%	2%
Opossum	3.5E+00	2.1E+01	6.5E+03	4.8E+03	207%	122%
Shrew	5.1E+02	3.0E+03	1.4E+02	9.9E+01	5060%	2979%
Skunk	2.2E+00	1.3E+01	2.6E+03	1.9E+03	128%	75%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.3.J. High Estimate of Exposure and Risk to Ohio Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDD (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	2.2E+02	1.2E+03	9.3E+01	6.4E+01	2175%	1193%
Mole	3.1E+02	1.7E+03	8.2E+02	5.6E+02	3085%	1691%
Otter	8.1E-02	4.4E-01	3.8E+02	2.6E+02	5%	3%
Opossum	6.4E+00	3.5E+01	1.2E+04	8.1E+03	376%	206%
Shrew	9.2E+02	5.0E+03	2.4E+02	1.7E+02	9171%	5028%
Skunk	3.9E+00	2.2E+01	4.8E+03	3.3E+03	232%	127%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.3.K. High Estimate of Exposure and Risk to Maine Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.5E+00	7.5E+00	6.4E-01	4.0E-01	15%	8%
Mole	2.1E+00	1.1E+01	5.7E+00	3.5E+00	21%	11%
Otter	5.6E-04	2.8E-03	2.6E+00	1.6E+00	0%	0%
Opossum	4.4E-02	2.2E-01	8.1E+01	5.1E+01	3%	1%
Shrew	6.3E+00	3.2E+01	1.7E+00	1.1E+00	63%	32%
Skunk	2.7E-02	1.4E-01	3.3E+01	2.1E+01	2%	1%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.3.L. High Estimate of Exposure and Risk to Wisconsin Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	1.4E+01	1.6E+02	5.8E+00	8.5E+00	135%	159%
Mole	1.9E+01	2.3E+02	5.1E+01	7.5E+01	191%	225%
Otter	5.0E-03	5.9E-02	2.4E+01	3.5E+01	0%	0%
Opossum	4.0E-01	4.7E+00	7.3E+02	1.1E+03	23%	27%
Shrew	5.7E+01	6.7E+02	1.5E+01	2.2E+01	569%	670%
Skunk	2.4E-01	2.9E+00	3.0E+02	4.4E+02	14%	17%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Table D.3.M. High Estimate of Exposure and Risk to Mississippi Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Armadillo	6.2E-01	0.0E+00	1.3E+03	0.0E+00	37%	0%
Bat	2.1E+01	0.0E+00	9.2E+00	0.0E+00	215%	0%
Mole	3.0E+01	0.0E+00	8.1E+01	0.0E+00	304%	0%
Otter	7.9E-03	0.0E+00	3.8E+01	0.0E+00	0%	0%
Opossum	6.3E-01	0.0E+00	1.2E+03	0.0E+00	37%	0%
Shrew	9.0E+01	0.0E+00	2.4E+01	0.0E+00	904%	0%
Skunk	3.9E-01	0.0E+00	4.7E+02	0.0E+00	23%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for armadillo, otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for armadillo, otter, opossum, and skunk.

Table D.3.N. High Estimate of Exposure and Risk to Pennsylvania Mammals

Organism	Daily Dose of TCDD (ng/kg/day)	Daily Dose of TCDF (ng/kg/day)	Steady state body burden of TCDD (ng)	Steady state body burden of TCDF (ng)	Comparison to LOAEL for TCDD (percent)	Comparison to LOAEL for TCDF (percent)
Bat	3.4E-01	1.0E-01	1.5E-01	5.5E-03	3%	0%
Mole	4.9E-01	1.5E-01	1.3E+00	4.8E-02	5%	0%
Otter	1.3E-04	3.8E-05	6.0E-01	2.2E-02	0%	0%
Opossum	1.0E-02	3.0E-03	1.9E+01	6.9E-01	1%	0%
Shrew	1.4E+00	4.3E-01	3.8E-01	1.4E-02	14%	0%
Skunk	6.2E-03	1.9E-03	7.5E+00	2.8E-01	0%	0%

1) Comparison to LOAEL of 10 ng/kg/day TCDD for bat, mole, and shrew; comparison to LOAEL of 1.7 ng/kg/day TCDF for otter, opossum, and skunk.

2) Comparison to LOAEL of 100 ng/kg/day TCDF for bat, mole, and shrew; comparison to LOAEL of 17 ng/kg/day TCDF for otter, opossum, and skunk.

Appendix E. Sample Calculations for Selected Exposure Pathways

EXAMPLE CALCULATION FOR SOIL CONCENTRATION, LAND APPLICATION
MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanantion*
1. Estimate sludge application rate		58000	kg/ha/yr	58000	
2. Estimate incorporation depth		15	cm	15	
3. Calculate incorporation volume	(incorporation depth) * (10000) * (10000)	1500000000	cm3/ha	15*10000*10000	
4. Estimate soil density		1.8	gm/cm3	1.8	
5. Calculate the mass of soil	(density) * (volume)	2700000000	gm/ha	1500000000*1.8	
6. Determine the sludge concentration		681	ppt	681	
7. Convert sludge concentration units to kg/kg	(sludge ppt)/ 1,000,000,000,000	6.81E-10	kg/kg	681/1000000000000	
8. Calculate the mass of contaminant	(application rate) * (sludge concentration)	3.95E-05	kg/ha/yr	58000*0.0000000007	

9. Calculate soil concentration for each year as follows					
9.a. Calculate mass of contaminant in soil	**(mass of contaminant) + ((mass of soil) * concentration in soil)/ conversion factor))**	**3.95E-05**	**kg/ha**	0.0000395+((2700000000*0)/1000000)	
9.b. Calculate the mass of soil contaminated	**(mass of soil) + (application rate)**	**2.76E+06**	**kg/ha**	2700000+58000	
9.c. Calculate yearly average soil concentration	**((mass of contaminant in mg/ha)/ (mass of soil))/(factor of 2 to determine average over year)**				
e.g., year 1:		**1.43E-05**	**mg/kg**	0.0000395*1000000/2760000	
10. Estimate application period		**70**	**years**	70	

10. Calculate average soil concentration over application period	(yearly concentrations/70)	3.00E-04	mg/kg	0.0003	If the application is less than 70 years the remaining years in the 70 year period are averaged in at the concentration at the end of the application period. This is appropriate since the model assumes no decay over a 70 year life span.

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
1. Estimate soil concentration		6.20E-05	mg/kg	0.000062	Assumed to equal average sludge concentration
2. Estimate contaminated land area		12.14	ha/year	12.14	U.S. EPA summary of data on industrial non-hazardous disposal practices (1985)
3. Estimate "C" ratio		1.1	unitless	1.1	Assumes SMA is 90% covered by vegetation and is surrounded by pasture land
4. Estimate "P" ratio		1	unitless	1	Assumes no support practices
5. Estimate distance from SMA to stream		152.4	meters	152.4	See Table 2.1.G.
6. Estimate drainage area of receiving stream		1259000	ha	1295000	Assumes a major stream
7. Obtain Koc value for TCDD		1.00E+07	unitless	1*10000000	
8. Estimate organic carbon in sediment		1	percent	1	Assumes organic carbon content of sediment equals organic

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS:
BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
9. Calculate Kd, the partitioning coefficient	Koc x percent organic carbon	1.00E+05	unitless	1*10000000*(0.01)	carbon content of soil
10. Estimate human consumption of fish		6.5	grams/day	6.5	See Table 2.1.G.
11. Estimate absorption from fish		90	percent	90	See Table 2.1.G.
12. Estimate percent of fish that is contaminated		100	percent	100	
13. Calculate the sediment delivery ratio for the SMA to the stream	0.77* (distance to stream)exp-0.22	2.55E-01		0.77*(152.4^-0.22)	See Appendix B
14. Calculate the drainage area sediment delivery ratio	0.87* (drainage area)exp-0.125	1.50E-01		0.87*(1295000^-0.125)	See Appendix B

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
15. Determine the sediment concentration before partitioning by calculating the sediment delivered from the SMA as a percent of the total sediment delivered to the stream. This calculation proceeds in the following 4 steps:					
15.a. Calculate the numerator of the ratio from the characteristics of the SMA	(SMA area) * ("C") * ("P") * (SMA SDR)	3.41E+00		12.14*1.1*1*(0.255)	
15.b. Calculate the denominator of the ratio from the characteristics of the drainage area	((drainage area - SMA area) * drainage area SDR) + result from step 15.a.	1.94E+05		((1295000-12.14)*0.15)+3.41	
15.c. Divide the value from step 15.a. by the value from step 15.b.		1.76E-05		3.41/194000	
16. Multiply by the soil concentration		1.09E-09	mg/kg	0.000062*0.0000176	

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
17. Partition the contaminant between water and sediment to determine sediment concentration	(sediment concentration from step 16) * (Kd/(1+Kd)	1.09E-09	mg/kg	0.0000000011*(100000/(1+100000))	
18. Estimate a fish to sediment ratio		0.0967		0.0967	See Table 2.1.G.
19. Estimate the concentration in the filet vs. in the whole fish		0.5		0.5	See Table 2.1.G.
20. Calculate filet concentration	(sediment concentration) * (fish:sediment ratio for TCDD) * (filet concentration vs. whole body concentration)	5.27015000E-11	mg/kg	0.0000000011*0.0967*0.5	
21. Calculate exposure	((fish consumption) * (filet concentration) * (percent of fish that is contaminated/100) /body weight	4.89E-15	mg/kg/day	(6.5/1000*5.2700000E-11*1)/70	Fish consumption is divided by 1000 to change units from grams to kilograms
22. Calculate dose	1.77E-10 exposure * absorption	4.40E-15	mg/kg/day	4.8900000E-15*0.9	

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
23. Estimate population density		124	people/sq. mile	124	
24. Estimate population exposed per landfill	drainage area * population density	620000	people	5000*124	Drainage area is converted to square miles
25. Estimate total population exposed for all landfills	population exposed per landfill * number of states with landfills	14260000	people	620000*23	Assumes that landfills in the same state affect the same people
26. Estimate average exposure	Dose * number of landfills/ number of states with landfills	1.12869565E-14	mg/kg/day	4.4000000E-15*59/23	The average dose is weighted for each person affected by the average landfills in a state to reflect overlapping contamination
27. Calculate risk	dose * potency	3E-09	tumors/lifetime	1.1290000E-14*273000	

EXAMPLE CALCULATION FOR FISH CONSUMPTION, LANDFILLS: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
28. Calculate cases per year	typical risk * population/life expectancy	6E-04	cases/year	0.0000000031*14260000/70	

The above calculation corresponds to the typical risk for landfills shown on page ix Table D. of the report. In this table risks from furan and dioxin are combined with a resulting average risk of 7 x 10exp-9. Dioxin contributes 43 percent of this risk, or approximately 3 x 10exp-9.

The above formulas are used with different input values to determine the MEI risks from the following pathways:

Risk from ingestion of surface water contaminated with furans from runoff from landfills
Risk from ingestion of surface water contaminated with dioxin from runoff from surface impoundments
Risk from ingestion of surface water contaminated with furans from runoff from surface impoundments
Risk from ingestion of surface water contaminated with dioxin from runoff from land application
Risk from ingestion of surface water contaminated with furans from runoff from land application

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD: MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(1) Obtain outdoor soil concentration	outdoor soil conc.	330	ppt (ng/kg)	From Table 2.4.A., obtain TCDD sludge concentrations reported for the Mississippi agricultural land application sites. (Since the opportunity for significant dermal exposure is assumed to exist only if there may be individuals who live on the land application site, only agricultural sites are considered).
(2) Convert units.	outdoor soil conc. in ng/kg x (1 kg/1e6 mg) = soil conc. in ng/mg	3.30E-04	ng/mg	Convert from ng/kg to ng/mg for ease of calculation.
(3) Obtain indoor dust concentration	indoor/outdoor ratio	0.8	unitless ratio	From Table 2.4.C., obtain best estimate of ratio of indoor/outdoor contaminant concentrations reported in literature.
	indoor soil conc. = outdoor conc. x indoor/outdoor ratio	2.64E-04	ng/mg	Product of 3.30 e-4 ng/mg x 0.80.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD: MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(4) Estimate dose to young children from outdoor sources				
(4a) Estimate needed input parameters.	outdoor contact rate	0.5	mg/cm2	From Table 2.4.C, obtain best estimate for contact rate for children outdoors reported in the literature.
	time exposed outdoors	1565	hrs/year	From Table 2.4.C., obtain best estimate of number of hours spent outdoors for young children. The derivation of this value is described on the table.
	area of skin exposed	2100	cm2	From Table 2.4.C., obtain best estimate for the area of skin in contact with soil outdoors. The derivation of this value is described in the table.
	absorption rate	0.012	fraction/hr	Best estimate from Table 2.4.C for children.
	matrix effect	1%	percent	Best estimate from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD: MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(4b) Calculate dose to young children from outdoor sources.	Dose = outdoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	6.51E-02	ng/yr	Product of 3.3 e-4 ng/mg x 0.5 mg/cm2 x 2100 cm^2 x 1565 hrs/yr x 0.012/hr x 1%
(5) Estimate dose to young children from indoor sources				
(5a) Estimate needed input parameters.	indoor contact rate	0.056	mg/cm2	From Table 2.4.C, obtain best estimate of contact rate for children indoors reported in literature.
	time exposed indoors	4380	hr/yr	From Table 2.4.C, obtain best estimate number of hours spent indoors for young children. The derivation of this value is described on the table.
	area of skin exposed	500	cm2	From Table 2.4.C, obtain best estimate of area of skin exposed indoors. The derivation this value is described in Table 2.4.C.
	absorption rate	0.012	fraction/hr	Best estimate value from Table 2.4.C.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
	matrix effect	1%	percent	Best estimate value from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.
(5b) Calculate dose from indoor sources.	Dose = indoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	3.89E-03	ng/yr	Product of 2.8 e-4 ng/mg x 0.056 mg/cm2 x 500 cm2 x 4380 hours/yr x 0.012/hr x 1%
(6) Obtain total dose for young children				
(6a) Obtain total yearly dose	Dose (ng/year) = outdoor dose (ng/year) + indoor dose (ng/yr)	6.90E-02	ng/yr	Sum of 6.51e-2 ng/yr + 3.89e-3 ng/yr
(6b) Obtain daily dose in ng/kg/day.	Dose ng/kg/day = Dose (ng/yr) /365 days per year /16 kg body weight	1.18E-05	ng/kg/day	Result of (6.9e-2ng/yr)/(365 days)/(16 kg)
(7) Estimate dose to older children from outdoor sources				

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(7a) Estimate needed input parameters.	outdoor contact rate	0.5	mg/cm2	From Table 2.4.C, obtain best estimate for contact rate for children outdoors reported in the literature.
	time exposed outdoors	1824	hrs/year	From Table 2.4.C., obtain best estimate of number of hours spent outdoors for older children. The derivation of this value is described on the table.
	area of skin exposed	1600	cm2	From Table 2.4.C., obtain best estimate for the area of skin in contact with soil outdoors. The derivation of this value is described in the table.
	absorption rate	0.012	fraction/hr	Best estimate from Table 2.4.C for children.
	matrix effect	1%	percent	Best estimate from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.
(7b) Calculate dose from outdoor sources.	Dose = outdoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	5.78E-02	ng/yr	Product of 3.3 e-4 ng/mg x 0.5 mg/cm2 x 1600 cm2 x 1824 hours/yr x 0.012/hr x 1%

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD: MISSISSIPPI

Step	Input Parameter or Calculation	Value	Units	Explanation
(8) Estimate dose to older children from indoor sources				
(8a) Estimate needed input parameters.	indoor contact rate	0.056	mg/cm2	From Table 2.4.C, obtain best estimate of contact rate for children indoors reported in literature.
	time exposed indoors	1460	hr/yr	From Table 2.4.C, obtain best estimate number of hours spent indoors for older children. The derivation of this value is described on the table.
	area of skin exposed	400	cm2	From Table 2.4.C, obtain best estimate of area of skin exposed indoors. The derivation this value is described in Table 2.4.C.
	absorption rate	0.012	fraction/hr	Best estimate value from Table 2.4.C.
	matrix effect	1%	percent	Best estimate value from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(8b) Calculate dose from indoor sources.	Dose = indoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	1.04E-03	ng/yr	Product of 2.8 e-4 ng/mg x 0.056 mg/cm2 x 400 cm2 x 1460 hours/yr x 0.012/hr x 1%
(9) Obtain total dose to older children.				
(9a) Obtain dose in ng/yr.	Total dose (ng/yr) = outdoor dose(ng/yr) + indoor dose (ng/yr)	5.88E-02	ng/yr	Sum of 5.78e-2 ng/yr + 1.04 e-3 ng/yr
(9b) Obtain dose in ng/kg/day	Dose ng/kg/day = Dose (ng/yr) /365 days per year /35 kg body weight	4.60E-06	ng/kg/day	(5.88e-2 ng/yr)/(365 days)/(35 kg)
(10) Estimate dose to adults from outdoor sources				

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(10a) Estimate needed input parameters.	outdoor contact rate	3.5	mg/cm2	From Table 2.4.C, obtain best estimate of contact rate for adults doing yard work.
	time expcaed outdoors	1565	hrs/year	From Table 2.4.C., obtain best estimate of number of hours spent outdoors for adults. The derivation of this value is described on the table.
	area of skin exposed	1700	cm2	From Table 2.4.C., obtain best estimate for the area of skin in contact with soil outdoors. The derivation of this value is described in the table.
	absorption rate	0.012	fraction/hr	Best estimate from Table 2.4.C for adults.
	matrix effect	1%	percent	Best estimate from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.
(10b) Calculate adult dose from outdoor sources.	Dose = outdoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	3.69E-01	ng/yr	Product of 3.3 e-4 ng/mg x 3.5 mg/cm2 x 1700 cm2 x 1565 hours/yr x 0.012/hr x 1%

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(11) Estimate dose to adults from living space sources.				
(11a) Estimate needed input parameters.	indoor contact rate	0.056	mg/cm2	From Table 2.4.C, obtain best estimate for contact rate for adults in living space (not attic).
	time exposed indoors	4380	hr/yr	From Table 2.4.C, obtain best estimate of number of hours spent indoors for adults. The derivation of this value is described on the table.
	area of skin exposed	900	cm2	From Table 2.4.C., obtain best estimate of area of skin exposed indoors. The derivation this value is described in Table 2.4.C.
	absorption rate	0.012	fraction/hr	Best estimate from Table 2.4.C for adults.
	matrix effect	1%	percent	Best estimate from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(11b) Calculate dose from living space sources.	Dose = indoor soil concentration, ng/mg x contact rate (mg/cm2) x area of skin exposed (cm2) x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	6.99E-03	ng/yr	Product of 2.8 e-4 ng/mg x 0.056 mg/cm2 x 900 cm2 x 4380 hours/yr x 0.012/hr x 1%
(12) Estimate dose to adults from exposure in attic.				
(12a) Estimate needed input parameters.	direct dermal contact rate while cleaning attic	1.8	mg/cm2	From Table 2.4.C, obtain reported literature value for contact rate for adults working in a closed space (i.e, an attic).
	area of skin exposed	1700	cm2	From Table 2.4.C., obtain best estimate of area of skin exposed indoors. The derivation of this value is described in Table 2.4.C.
	mg of dirt on skin from direct contact = direct dermal contact rate (mg/cm2) x area of skin exposed (cm2)	3060	mg	Product of 1.8 mg/cm2 x 1700 cm2.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	Input Parameter or Calculation	Value	Units	Explanation
	indirect dermal contact rate from being	110	mg	From Table 2.4.C. Hawley (1985) estimated that an adult is exposed to approximately 110 mg of dust from the surrounding air for a typical cleaning event of one hour.
	total mg on skin from attic work = mg from direct contact + mg from indirect contact	3170	mg	Sum of 3060 mg + 110 mg.
	amount of time attic dirt remains on skin (hours per year)	48	hours/yr	This value assumes the MEI engages in twelve cleaning events per year in the attic or other similar spaces. It also assumes that the dirt is left on the skin for 4 hours before it is washed off.
	absorption rate	0.012	fraction/hr	Best estimate from Table 2.4.C for adults.
	matrix effect	1%	percent	Best estimate from Table 2.4.C. This reflects the percent of the dioxin that can migrate from the sludge matrix to be available for absorption.
(12b) Estimate dose from attic sources.	Dose = indoor soil concentration, ng/mg x total mg on skin per cleaning event x time exposed (hrs/yr) x absorption rate (fraction/hr) x matrix effect (percent)	4.82E-03	ng/yr	Product of 2.8 e-4 ng/mg x 3170 mg x 48 hours/yr x 0.012/hr x 1%

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(13) Obtain total dose to adult.				
(13a) Obtain dose in ng/yr.	Total dose (ng/yr) = outdoor dose(ng/yr) + living space dose (ng/yr) + attic dose (ng/yr)	3.81E-01	ng/yr	Sum of 3.69e-1 ng/yr + 6.99e-3 ng/yr + 4.82e-3 ng/yr
(13b) Obtain dose in ng/kg/day.	Dose ng/kg/day = Dose (ng/yr) /365 days per year /70 kg body weight	1.49E-05	ng/kg/day	[(3.81e-1 ng/yr)/(365 days)]/(70 kg)
(14) Obtain risk estimate.				
(14a) Obtain potency estimate for TCDD.	q1* for TCDD	2.73E+05	(mg/kg/day)-1	Potency estimate derived by CAG; adjusted for built in absoprtion factor of 0.55 (see memo from C. Cinalli, dated July 21, 1989).
(14b) Obtain weighted average daily dose over lifetime.	Daily dose = young child dose*(5/70) + older child dose*(5/70) + adult dose*(60/70)	1.39E-05	ng/kg/day	[1.18 e-5 ng/kg/day x (5/70)] + [4.60 e-6 ng/kg/day x (5/70)] + [1.49 e-5 ng/kg/day x(60/70)]. The dose for each age group is weighted by the fraction of a lifetime spent in each age group.

EXAMPLE CALCULATION FOR DERMAL EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD:
MISSISSIPPI

Step	*Input Parameter or Calculation*	*Value*	*Units*	*Explanation*
(14c) Convert dose from ng/kg/day to mg/kg/day.	Dose (mg/kg/day) = [Dose (ng/kg/day)]/[1 mg/1e6 ng]	1.39E-11	mg/kg/day	Result of [1.39 e-5]/[1e6]. This conversion makes the units of the dose compatible with the units of the q1* estimate.
(14d) Obtain risk estimate.	Risk = q1* [(mg/kg/day)-1] x daily dose (mg/kg/day)	3.80E-06	risk per lifetime	Product of 2.73 e5 x 1.39e-11.
(14e) Obtain population risk	Pop risk = individual risk x size of exposed population	1.03E-04		Product of 3.8 e-6 x 27 persons. Size of exposed population on agricultural land application sites in MS is 27 persons. Derivation explained in text.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	*Input Parameter/Calculation*	*Value*	*Units*	*Explanation*
(1) Obtain outdoor soil concentration	outdoor soil conc.	330	ppt (ng/kg)	From Table 2.4.A., obtain TCDD sludge concentrations reported for MS agricultural land application site. Since the opportunity for significant direct ingestion is assumed to exist only if there may be individuals who live on the land application site, only agricultural land application sites are considered.
(2) Obtain indoor dust concentration	indoor/outdoor ratio	0.8	unitless ratio	From Table 2.4.I., obtain best estimate of ratio of indoor/outdoor contaminant concentrations reported in literature.
	indoor dust conc. = outdoor conc. x indoor/outdoor ratio	264	ng/kg	Product of 330 ng/kg x 0.80.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	Input Parameter/Calculation	Value	Units	Explanation
(3) Estimate dose to young children (ages 1-6)				
(3a) Estimate necessary input parameters.	total soil ingestion	0.0002	kg/day	From Table 2.4.1., obtain best estimate of soil ingestion rate reported for children in the OSW Directive "Interim Final Guidance on Soil Ingestion Rates". This value is 0.2 grams per day, or 0.0002 kilograms per day.
	percent of soil ingested from outdoor sources	54.5%	percent	From Table 2.4.1., obtain the percent of total daily soil ingestion that comes from outdoor sources. This value was obtained from "Estimating Exposures to 2,3,7,8-TCDD" (EPA, 1988).
	percent of soil ingested from indoor sources	45.5%	percent	To obtain the percent of total soil ingested from indoor sources, subtract percent from outdoor sources from 100%.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	Input Parameter/Calculation	Value	Units	Explanation
	percent of ingested soil from contaminated area	10%	percent	From Table 2.4.1., obtain best estimate of percent ingested from contaminated area. This is the same value that was assumed in assessment of municipal sludge risks (EPA, OWRS, 1989).
(3b) Calculate outdoor dose to young child	Outdoor dose = outdoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from outdoor sources x percent of soil from the contaminated area	3.60E-03	ng/day	Product of 330 ng/kg x 0.0002 kg/day x 55% x 10%
(3c) Calculate indoor dose to young child	Indoor dose = indoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from indoor sources x percent of dust from contaminated sources	2.40E-03	ng/day	Product of 264 ng/kg x 0.0002 kg/day x 45% x 10%
(3d) Calculate total dose to young child	Total dose = sum of indoor and outdoor sources	6.00E-03	ng/day	Sum of 3.60e-3 ng/day + 2.40e-3 ng/day
(4) Estimate dose to older children (ages 7-12)				

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	*Input Parameter/Calculation*	*Value*	*Units*	*Explanation*
(4a) Estimate necessary input parameters.	total soil ingestion	0.0001	kg/day	From Table 2.4.I., obtain best estimate of soil ingestion rate for older children. We used lower end of range reported for all children in the OSW Directive "Interim Final Guidance on Soil Ingestion Rates". This value is 0.1 grams per day, or 0.0001 kilograms per day.
	percent of soil ingested from outdoor sources	87.5%	percent	From Table 2.4.I., obtain the percent of total daily soil ingestion that comes from outdoor sources. This value was obtained from "Estimating Exposures to 2,3,7,8-TCDD" (EPA, 1988).
	percent of soil ingested from indoor sources	12.5%	percent	To obtain the percent of total soil ingested from indoor sources, subtract percent from outdoor sources from 100%.
	percent of ingested soil from contaminated area	10%	percent	From Table 2.4.I., obtain best estimate of percent ingested from contaminated area. This is the same value that was assumed in assessment of municipal sludge risks (EPA, OWRS, 1989).

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	*Input Parameter/Calculation*	*Value*	*Units*	*Explanation*
(4b) Calculate outdoor dose to older child	Outdoor dose = outdoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from outdoor sources x percent of soil from the contaminated area	2.89E-03	ng/day	Product of 330 ng/kg x 0.0001 kg/day x 88% x 10%
(4c) Calculate indoor dose to older child	Indoor dose = indoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from indoor sources x percent of dust from contaminated sources	3.30E-04	ng/day	Product of 264 ng/kg x 0.0001 kg/day x 13% x 10%
(4d) Calculate total dose to older child	Total dose = sum of indoor and outdoor	3.22E-03	ng/day	Sum of 2.89e-3 ng/day + 3.30e-4 ng/day
(5) Estimate dose to adults				
(5a) Estimate necessary input parameters.	total soil ingestion	0.00002	kg/day	From Table 2.4.1., select best estimate of soil ingestion rate for adults reported in the OSW Directive "Interim Guidance on Soil Ingestion Rates". This value was 0.02 grams per day, or 0.00002 kilograms per day.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD

MISSISSIPPI

Step	Input Parameter/Calculation	Value	Units	Explanation
	percent of soil ingested from outdoor sources	93.0%	percent	From Table 2.4.1., obtain the percent of total daily soil ingestion that comes from outdoor sources. This value was obtained from "Estimating Exposures to 2,3,7,8-TCDD" (EPA, 1988).
	percent of soil ingested from indoor sources	7.0%	percent	To obtain the percent of total soil ingested from indoor sources, subtract percent from outdoor sources from 100%.
	percent of ingested soil from contaminated area	10%	percent	From Table 2.4.1., obtain best estimate of percent ingested from contaminated area. This is the same value that was assumed in assessment of municipal sludge risks (EPA, OWRS, 1989).
(5b) Calculate outdoor dose to adult	Outdoor dose = outdoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from outdoor sources x percent of soil from the contaminated area	6.14E-04	ng/day	Product of 330 ng/kg x 0.00002 kg/day x 93% x 10%

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	Input Parameter/Calculation	Value	Units	Explanation
(5c) Calculate indoor dose to adult	Indoor dose = indoor conc. (ng/kg) x soil ingestion rate (kg/day) x percent from indoor sources x percent of dust from contaminated sources	3.70E-05	ng/day	Product of 264 ng/kg x 0.00002 kg/day x 7% x 10%
(5d) Calculate total dose to adult	Total dose = sum of indoor and outdoor	6.51E-04	ng/day	Sum of 6.14e-4 ng/day + 3.70e-5 ng/day.
(6) Estimate total lifetime dose.				
(6a) Estimate weighted average dose for each age group.	weighted young child dose = (dose/kg body weight) x 5/70	2.68E-05	ng/kg/day	[(6.0 e-3 ng/day)/16 kg] x (5/70) The dose is weighted by 5/70, the fraction of a lifetime spent in the "young child" age group. Dose in ng/dy is divided by 16 kg to obtain dose in ng/kg/dy.
	weighted older child dose = (dose/kg body weight) x 5/70	6.57E-06	ng/kg/day	[(3.22e-3 ng/day)/35 kg] x (5/70) The dose is weighted by 5/70, the fraction of a lifetime spent in the "older child" age group. Dose in ng/dy is divided by 35 kg to obtain dose in ng/kg/dy.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	*Input Parameter/Calculation*	*Value*	*Units*	*Explanation*
	weighted adult dose = (dose/kg body weight) x 60/70	7.97E-06	ng/kg/day	[(6.51e-4 ng/day)/70 kg] x (60/70) The dose is weighted by 60/70, the fraction of a lifetime spent in the "adult" age group. Dose in ng/dy is divided by 70 kg to obtain dose in ng/kg/dy.
(6b) Obtain average daily dose to over lifetime.	average daily dose over lifetime =	4.13E-05	ng/kg/day	(2.68e-5 + 6.57e-6 + 7.97e-6) ng/kg/day Sum of weighted doses from three age groups.
(7) Estimate lifetime incremental risk.				
(7a) Obtain necessary input parameters.	average daily dose over lifetime in mg/kg/da = dose (ng/kg/day) x (1 mg/1e6 ng)	4.13E-11	mg/kg/day	(4.13 e-5 ng/kg/day) x (1 mg/1e6 ng). Dose is converted to mg/kg/day to match units of q1*.

EXAMPLE CALCULATION FOR DIRECT INGESTION EXPOSURE, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM TCDD
MISSISSIPPI

Step	*Input Parameter/Calculation*	*Value*	*Units*	*Explanation*
	GI bioavailability of dioxin from soil =	0.45	fraction	From Table 2.4.1., obtain best estimate of gastrointestinal bioavailability reported in FDA memo dated 6/22/89. This value was used for both dioxin and furan.
	q1* for TCDD	2.73E+05	(mg/kg/day)-1	Value for q1* of 1.5 e5 developed by CAG. This value is then adjusted by dividing by built-in absorption factor of 0.55 (described in memo from C. Cinalli, dated 7/21/89).
(7b) Calculate risk.	Risk = Dose (mg/kg/day) x Bioavailability (fraction) x q1* ((mg/kg/day)-1)	5.07E-06	risk per lifetime	4.13e-11 mg/kg/day x 0.45 (bioavailability factor) x 2.73e5 (mg/kg/day)-1
(8) Calculate population risk.	Population risk = individual risk x size of exposed population /length of a typical lifespan	1.96E-06	cases per year	[(5.07e-6 risk per lifetime) x 27 persons]/70 years in an average lifetime. The size of the exposed population on agricultural sites in MS is 27 persons. The derivation of this value is given in the text.

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
1. Estimate soil concentration	see attached	3.30E-04	mg/kg	0.0003	
2. Estimate total sludge amended area		405	ha	405	From personal communication with state official
3. Determine crops produced on SMA and percentages of the land devoted to each crop:					
wheat		23	percent	23	
corn		28	percent	28	From personal communication with state official
soybeans		39	percent	39	
pasture		10	percent	10	
4. Estimate crop yields					
wheat		94	bushels/ha	94	From USDA Agricultural Statistics
corn		173	bushels/ha	173	
soybeans		59	bushels/ha	59	
5. Estimate percent of each crop that is fed to animals					
wheat		0	percent	0	
corn		90	percent	90	From personal communication with county official
soybeans		40	percent	40	
6. Determine animals consuming corn					
beef cows					
hogs					From personal communication with county official
chicken					
dairy cows					

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
7. Estimate the percent of corn fed to each animal based on the number of each animal in the state and the average consumption of each animal					
7.a. Number of animals in MS					
beef cows		1588000	beef cows	1588000	From USDA Agricultural Statistics, 1985
hogs		285000	hogs	285000	
chicken		5000000	chicken	5000000	
7.b. Average consumption per head					
beef cows		5994	lbs/head/yr	5994	From USDA Agricultural Statistics, 1985
hogs		1200	lbs/head/yr	1200	
chicken		28	lbs/head/yr	28	
7.c. Average consumption by animals	number of each animal * consumption per head				
beef cows		9.52E+09	lbs/yr	1588000*5994	
hogs		3.42E+08	lbs/yr	285000*1200	
chicken		1.40E+08	lbs/yr	5000000*28	
7.d. Percent of consumption by each animal	(each animal consumption)/ (total beef, hog, and chicken consumption)				
beef cows		0.95	percent	9520000000/(9520000000+342000000+140000000)	
hogs		0.03	percent	342000000/(9520000000+342000000+140000000)	
chicken		0.01	percent	140000000/(9520000000+342000000+140000000)	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
8. Determine animals consuming animal soybeans and percent of soybeans to the animals					
catfish		100	percent	100	While other animals also consume soybeans, catfish consume more than any other animal. reasons and implications for assuming that all animal soybeans are fed to catfish are discussed in the report.
9. Estimate the percent of cows' consumption that is made up of soil		8	percent	8	See Table 2.4.D
10. Estimate the animal yield from corn-equivalent feed					
beef		0.07	lb of beef/lb of feed	0.07	From USDA Agricultural Statistics, 1985
milk		0.97	lb of milk/lb of feed	0.97	From USDA Agricultural Statistics, 1985
hog		0.17	lb of hog/log of feed	0.17	From USDA Agricultural Statistics, 1985
chicken		0.4	lb of chicken/lb of feed	0.4	From USDA Agricultural Statistics, 1985
catfish		0.5	lb of catfish/lb of feed	0.5	From Harford County, MS extension agent
11. Estimate percent of each animal product that is fat					
beef		10	percent	10	
dairy		4	percent	4	See Table 2.4.D
hog		7	percent	7	
chicken		10	percent	10	
12. Estimate the contaminant concentration in a filet of fish vs. in the whole body		50	percent	50	EPA bioconcentration factors are given for fish filet rather than for fat.

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
13. Estimate the beef yield from grazing					
13.a. Estimate the percentage of pasture acres in the two counties applying sludge agriculturally that is sludge-amended	(sludge-amended land)/total pasture land	2.33E-03	unitless	100/43000	From county extension agent
13.b. Estimate the number of cows in the two counties		24000	cows	24000	From county extension agent
13.c. Estimate the percent of cows marketed per year		54	percent	54	USDA Agricultural Statistics , 1985
13.d. Calculate number of marketed cows grazed on sludge-amended land	(number of cows) (percent of cows marketed per year) * (percent of pasture land that is sludge amended)	25.92		24000*0.54*0.002	
13.e. Estimate average quantity of beef product produced per head		433	lbs/head	433	From USDA Agricultural Statistics
13.f. Calculate the quantity of beef product from cows grazed on sludge-amended land	(quantity produced per head) * (number of marketed cows grazed on sludge-amended land) * (conversion to kgs)	5084	kgs	433*25.92*0.453	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
14. Estimate percent of crop weight that is dry matter					
grain		26	percent	26	See Table 2.4.D.
soybean		8	percent	8	
grass		5	percent	5	
15. Estimate plant uptake rates (dry weight)					
wheat		2	percent	2	See Table 2.4.D.
corn		2	percent	2	
soybeans		2	percent	2	
grass		2	percent	2	
16. Estimate animal bio-concentration factors (consuming dry weights, yielding fresh weights)					
beef fat		400	percent	400	See Table 2.4.D.
dairy fat		400	percent	400	
hog fat		400	percent	400	
chicken fat		400	percent	400	
fish filet		5	percent	5	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
17. Estimate the percentage that contaminated food contributes to each animal's diet					Figures from Table 2.4.E are adjusted to include soil consumption where appropriate
corn					
beef	(percentage from Table 2.4.E) * (1-percent of diet that is soil)	0.02		6.3/253.16*0.92	
dairy		0.07		19.7/249.94*0.92	
hogs		0.77		43.9/57.23	
chicken		0.59		9.5/16.15	
grass					
beef		0.37		102.51/253.16*0.92	
dairy		0.37		99.34/249.94*0.92	
soybeans					
catfish		0.50		.50	From Delta Western Feed Mills
18. Estimate human absorption of of contaminant when consumed in the following vehicles:					
wheat		70	percent	70	See Table 2.4.D.
corn		70	percent	70	
soybeans		70	percent	70	
beef		95	percent	95	
dairy		95	percent	95	
hogs		95	percent	95	
chicken		95	percent	95	
catfish		95	percent	95	
19. Calculate the amount of contaminated food available for animal and human consumption					

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
19.a. Estimate the land area devoted to producing each crop	(total sludge area) * (percent to each crop)				
wheat		93	ha	405*0.23	
corn		113	ha	405*0.28	
soybeans		158	ha	405*0.39	
grass		41	ha	405*0.1	
19.b. Estimate crop yield	(land area) * (yield per land area)				
wheat		8747	bushels	93.15*93.9	
corn		19618	bushels	113.4*173	
soybeans		9366	bushels	157.95*59.3	
19.c. Estimate crop yield that is fed to animals	(crop yield) * (percent to animals)				
wheat		0	bushels	8746.785*0	
corn		17656	bushels	3642.408*0.9	
soybeans		3747	bushels	9366.435*0.4	
19.d Estimate yield of each crop to each animal	(crop yield to animals) * (percent to each animal)				
corn					
beef		16949.76	bushels	17656*0.96	
dairy		0	bushels	17656*0	
hogs		529.68	bushels	17656*0.03	
chicken		176.56	bushels	17656*0.01	
soybeans					
catfish		3747	bushels	3747*1	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
20. Calculate the crop concentrations	(soil concentration) * (plant uptake) * (percent dry matter)				
wheat		1.56E-06	mg/kg	0.0003*0.02*0.26	
corn		1.56E-06	mg/kg	0.0003*0.02*0.26	
soybeans		4.80E-07	mg/kg	0.0003*0.02*0.08	
grass		3.00E-07	mg/kg	0.0003*0.02*0.05	
21. Calculate the animal concentrations resulting from animals consuming contaminated crops	(crop concentration) * (animal bioconcentration) * (percent of animals' diet)				
corn					
beef fat		1.25E-07	mg/kg	0.00000156*4*0.02	
dairy fat		4.37E-07	mg/kg		
hog fat		4.80E-06	mg/kg	0.00000156*4*0.77	
chicken fat		3.68E-06	mg/kg	0.00000156*4*0.59	
soybeans					
catfish filet		1.20E-08	mg/kg	0.00000156*0.05*0.5	
grass					
beef fat		4.44E-07	mg/kg	0.0000003*4*0.37	
dairy fat		4.44E-07	mg/kg		
soil					
beef fat		9.60E-05	mg/kg	0.0003*4*0.08	
dairy fat		9.60E-05	mg/kg		
22. Total beef fat concentrations from corn, grass and soil	(concentration from corn) + (concentration from grass) + (concentration from soil)	9.66E-05	mg/kg	0.000000125+0.000000444+0.000096	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
23. Calculate the contaminant dose to humans through direct consumption of crops					
23.a. Calculate amount of contaminated crop consumed by humans	(contaminated crop produced) - (contaminated crop fed to animals) * (conversion from bushels to kilograms)				
wheat		220414	kgs	(8746.6-0)*25.2	
corn		49442	kgs	(19618-17656)*25.2	
soybeans		141630	kgs	(9367.07-3746.83)*25.2	
23.b. Calculate the contaminant ingested by humans as a result of crop consumption	(contaminated crop consumed by humans) * (crop contamination level)				
wheat		3.44E-01	mgs	220414*0.00000156	
corn		7.71E-02	mgs	49442*0.00000156	
soybeans		6.80E-02	mgs	141630*0.00000048	
23.c. Calculate typical population dose from direct consumption of contaminated crops	(available contaminant from 23.b.) * (human absorption) /(body weight)/(number of people consuming the contaminant) /(days per year)				
wheat		3.66E-14	mgs/kg body weight/da	0.344*0.65/70/239000000/365	
corn		8.21E-15	mgs/kg body weight/da	0.0771*0.65/70/239000000/365	
soybeans		7.24E-15	mgs/kg body weight/da	0.068*0.65/70/239000000/365	
24. Calculate the contaminant dose to humans resulting from consumption of animals fed contaminated corn					

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION:
BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
24.a. Calculate the amount of contaminated animal fat available for consumption	(bushels of corn fed to each animal) * (factor for conversion to kgs) * (animal yield per unit feed)*(percent of animal that is fat)/(percent of each animal's total consumption that is corn)				
beef		149490	kgs	16949*25.2*0.07*0.1/0.02	
dairy		0	kgs	0	
hogs		206	kgs	529*25.2*0.17*0.07/0.77	
chicken		301	kgs	176*25.2*0.4*0.1/0.59	
24.b. Calculate the contaminant ingested by humans as a result of consumption of animals fed contaminated corn	(amount of contaminated fat) * (contamination level)				
beef		1.87E-02	mgs	149490*0.000000125	
dairy		0.00E+00	mgs	0	
hogs		9.89E-04	mgs	206*0.0000048	
chicken		1.11E-03	mgs	301*0.00000368	
24.c Calculate typical population dose from consumption of animal fed contaminated corn	(available contaminant from 24.b) * (human absorption) /(body weight)/(number of people consuming the contaminant) /(days per year)				
beef		2.7561E-15	mgs/kg body weight/da	0.0187*0.9/(70*239000000*365)	
dairy		0	mgs/kg body weight/da	0	
hogs		1.4576E-16	mgs/kg body weight/da	0.000989*0.9/(70*239000000*365)	
chicken		1.6360E-16	mgs/kg body weight/da	0.00111*0.9/(70*239000000*365)	

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
25. Calculate the contaminant dose to humans resulting from consumption of animals fed contaminated soybeans					
25.a. Calculate the amount of contaminated fish filet available for consumption	(bushels of soybeans fed to catfish) * (factor for conversion to kgs) * (catfish yield per unit feed)/(percent of catfish consumption that is soybeans)	94420.116	kgs	3746.83*25.2*0.5/0.5	
25.b. Calculate the contaminant ingested by humans as a result of consumption of catfish fed contaminated soybeans	(amount of contaminated filet) * (contamination level)	1.13E-03	mgs	94420.116*0.000000012	
25.c Calculate typical population dose from consumption of catfish fed contaminated soybeans	(available contaminant from 25.b) * (human absorption) /(body weight)/(number of people consuming the contaminant) / days per year)	1.6655E-16	mgs/kg body weight/da	0.00113*0.9/(70*239000000*365)	
26. Calculate the contaminant dose to humans resulting from consumption of animals grazed on contaminated pasture					

EXAMPLE CALCULATION FOR DIETARY CONSUMPTION, LAND APPLICATION: BEST ESTIMATE FOR TYPICAL RISK FROM DIOXIN, MISSISSIPPI

Step	*Calculation*	*Value*	*Units*	*Formula*	*Explanation*
26.a. Calculate the amount of beef fat contaminated from grazing that is available for consumption	(contaminated animal yield from 13.f. above)*(percent of animal that is fat)	508.418	kgs	5084.18*0.1	
26.b. Calculate the contaminant ingested by humans as a result of consumption of beef cattle grazed on contaminated land	(amount of contaminated beef fat) * (contamination level)				
contamination from grass		2.26E-04	mgs	508.418*0.000000444	
contamination from soil		4.88E-02	mgs	508.418*0.000096	
26.c Calculate typical population dose from consumption of beef fa grazed on contaminated land	(available contaminant from 27.c) * (human absorption) /(body weight)/(number of people consuming the contaminant) /(days per year)				
contamination from grass		3.33E-17	mgs/kg body weight/da	0.000226*0.9/(70*239000000*365)	
contamination from soil		7.19E-15	mgs/kg body weight/da	0.0488*0.9/(70*239000000*365)	
27. Sum typical population exposure from all sources		5.531E-14	mgs/kg body weight/da		
28. Calculate risk	(dose) * (potency)	1.66E-08	tumors/lifetime	5.3320000E-14*300000	

The above methodology was repeated to determine typical population risk from TCDD applied to agricultural land in the state of Pennsylvania. The resulting risk was 5 x 10exp -11. Therefore the risk from Mississippi outweighs the risk from Pennsylvania by approximately three orders of magnitude. The typical population risk of 1.7 x 10exp -8 can be compared to the value in Table G, page xiii. (Values differ slightly due to the precision of the computer calculations reflected in Table G verses the rounding in the above calculations.)

Appendix F. Update to Ecological Risk Assessment

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JUN 26 1990

MEMORANDUM

OFFICE OF
PESTICIDES AND TOXIC SUBSTANCES

SUBJECT: EEB Update of Risks in the Aquatic and Terrestrial Environments made for the Dioxin-in-Paper Project

FROM: William S. Rabert William S. Rabert
Environmental Effects Branch
Health and Environmental
Review Division (TS-796)

TO: Pat Jennings
Exposure Assessment Branch
Exposure Assessment Division (TS-798)

THRU: Maurice Zeeman, Ph.D. M. Zeeman
Acting Chief
Environmental Effects Branch
Health and Environmental
Review Division (TS-796)

Attached to this memorandum is the revised update of risks to fish and wildlife. Comments from six reviewers were reviewed and incorporated as time permitted in 48 hours. Comments were received from Priscilla Halloran, Al Rubin, Pat Jennings, Jim Kwiat, Lois Dicker, and Gary Grindstaff.

Update Summary

EEB was asked by the dioxin work group to update the aquatic and terrestrial portions of the ecological risk assessment with recent information and to evaluate the assumptions used in the terrestrial model. Additional information on dioxin toxicity and exposure to fish and wildlife have been received, analyzed, and some new ecological concerns identified since the original risk assessments were completed. The new information reaffirms the earlier assessments of risks to aquatic and terrestrial wildlife. Exposure concentrations of TCDD and TCDF may adversely affect local fish and wildlife populations exposed to pulp mill effluents and dioxin-contaminated sludge applied to land and forested areas.

This update identifies concerns for TCDD contamination of some highly sensitive aquatic areas that pose special concerns. The Great Lakes are sensitive laurentian environments where the introduction of TCDD could pose potentially severe problems. Commercial and sport fisheries are economically important in the Great Lakes. Effluent or atmospheric inputs of TCDD into these lakes are likely to affect fish and wildlife populations and consumption of exposed fish could pose a human health risk. High TCDD levels in fish in the Great Lakes continue to be a health concern. At least six chlorine-bleaching kraft or sulfite pulp mills are located on the edge of the Great Lakes and another two mills discharge into rivers that flow into the Great Lakes. It is uncertain what other sensitive bodies of water, such as productive estuarine areas, also receive effluents from one or more pulp mills. It is unclear whether modelers considered multiple dicharges from adjacent pulp mills into a single aquatic area in their estimation of exposure levels.

The risk assessments do not include toxic effects resulting from the other chlorinated organic compounds formed in the pulp and paper process. Estimates of environmental concentrations for these chemicals were unavailable. Additional toxic effects on fish and wildlife might also be expected from these other chlorinated chemicals.

One aspect which has not been addressed in either risk assessment is the impact of chlorinated dioxins and furans on populations of endangered species. It has become evident that some endangered species are exposed to concentrations of dioxin in effluents from some pulp and paper mills. Other endangered species also may be exposed to dioxins at sites where land application of dioxin-contaminated sludges is permitted. Given the myriad conditions of exposure, it is unclear whether local endangered species populations are at risk by exposure to TCDD or TCDF produced during chlorination of pulp in the paper-making process.

AN UPDATE ON THE ENVIRONMENTAL EFFECTS OF TCDD AND TCDF RELEASES FROM PULP AND PAPER MILLS ON AQUATIC AND TERRESTRIAL ANIMALS

William S. Rabert

Environmental Effects Branch
Health and Environmental Review Division
Office of Toxic Substances

June 1990

Table of Contents

Page

I. Introduction 1

II. Hazard Assessment Summary

- A. Fate and Toxicity of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD) 1
- B. Fate and Toxicity of 2,3,7,8-Tetrachlorodibenzofuran (TCDF) 2

III. Risk Assessment Summary and Update

- A. Aquatic Risk Assessment for TCDD and TCDF from Mill Effluents 2
  - 1. Pulp Mill Effluent Risks to Fish 3
  - 2. Effluent Risks to Aquatic Plants and Herbivores 4
  - 3. Effluent Risks to Benthic Organisms 5
  - 4. Effluent Risks to Fish-eating Birds and Mammals 6
- B. Terrestrial Risk Assessment for Land Application of TCDD- and TCDF-contaminated Sludge
  - 1. Evaluation of the Abt Model 8
  - 2. Evaluation of the NCASI Study in Wisconsin 9
  - 3. Comparison of the Abt Estimates with NCASI Data 9
  - 4. Potential Effects of Land Application on Endangered Species 10

IV. Conclusions on Risk 10

V. References 12

VI. Tables (1 through 7) 14

Introduction

This update attempts to provide the latest assessment of TCDD risks to wildlife in aquatic and terrestrial environments. The original aquatic risk assessment drafted by the Office of Water did not include risks posed to birds and mammals feeding in contaminated aquatic habitats. Therefore, the Environmental Effects Branch (EEB) was asked to address these missing portions of the aquatic risk assessment.

EEB was also asked to critically review the Abt terrestrial risk assessment to understand the model and to determine whether the estimate of risks to wildlife were reasonable. A comparison was requested between Abt°s estimates of risk and the results of the Wisconsin study by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI).

I. Hazard Assessment Summary

A. Fate and Toxicity of 2,3,7,8-Tetrachlorodibenzo-p-dioxin (TCDD)

Chlorinated dioxins and furans are very highly toxic to fish, birds, and mammals (Table 1). The most toxic congener of polychlorinated dibenzo-p-dioxins appears to be 2,3,7,8-TCDD. TCDD has low water solubility (about 200 ng/L) and a high log P value (about 6.8). These two properties contribute to the ability of TCDD to bioaccumulate in organisms and enter the food web. Available bioconcentration tests have not been conducted for an adequate duration to reach a steady-state equilibrium in fish and many tests have grossly underestimated the bioconcentration factor (BCF) for TCDD. The longer the duration of the BCF test the higher the BCF estimate value. Estimates of BCF values for TCDD range from about 7,900 to 159,000 times the water concentration (Table 2).

TCDD is very persistent; the half-life in the human body is 7 to 10 years and in soil has been estimated to be 10-15 years. Dioxins may persist even longer in sediments, because compounds adsorbed to the sediments are less subject to degradation via photolysis, oxidation, and microbial action. The persistence of TCDD and its availability from sediments might pose a continuing problem for some time, even if TCDD were no longer released from pulp mills. TCDD is expected to volatilize during the chlorine bleaching process, pulp drying process, and even from pulp sludge and soils. The levels and effects of volatilized TCDD available for aerial transport and deposition has not been quantified in this risk assessment.

Fish appear to be the most sensitive tested species to TCDD. The ultimate chronic toxicity of TCDD to fish for non-lethal endpoints has not yet been determined. Mortality is normally delayed several days depending on the test concentration and the duration of exposure. A 56-day BCF test with rainbow trout produced 45 percent mortality at the lowest test concentration

(38 ppq --- estimated LC50 of 40 ppq). Nearly all mortality at the lowest concentration occurred after the 28-day exposure and continued throughout the 28-day depuration period. No cessation of death was apparent at the end of the test. Extrapolation of the final dose-response data for mortality suggests 5 to 10 percent lethality at 1 ppq. The time to lethality is extended by lower exposure concentrations and shorter exposures. Lethality has not been shown to be related to TCDD body burdens in fish. Indeed, the fish in bioconcentration tests have been found to die after TCDD levels have depurated significantly. Consequently, tissue concentrations of TCDD in fish cannot be used to specify the cause of death. The shortest reported TCDD exposure period was six hours, and even after that short exposure the fish subsequently died of TCDD toxicity on days 78, 118, 134, 136, and 139 (Branson et al., 1985).

B. Fate and Toxicity of 2,3,7,8-tetrachlorodibenzofuran (TCDF)

Chlorinated furans are more water soluble than dioxins and tend to bioconcentrate to a lesser degree. TCDF is less toxic than TCDD. Merhle et al (1988) reported the no-observed-effect concentration (NOEC) for TCDF based on growth effects as 0.41 ng/l, the lowest test concentration. In human health studies, the toxicity equivalent factor (TEF) for 2,3,7,8-tetrachlorodibenzofuran is about one-tenth that of 2,3,7,8-TCDD (U.S. EPA, 1989). In this report, the TEF value of 0.1 for TCDF was used to estimate risks to aquatic organisms, birds and mammals from mixtures of TCDD and TCDF.

II. Risk Assessment Summary and Update

A. Aquatic Risk Assessment for TCDD and TCDF from Mill Effluents

The in-stream water concentrations for TCDD and TCDF were calculated by Tetra Tech, Inc. (unpublished) for the Office of Water based on the effluent concentrations measured in the 104 mill study. Two dilution water models were used to derive the in-stream concentrations (i.e., the harmonic mean flow and the 7Q10 low flow values for the respective stream reaches). The 7Q10 low flow rate is defined as the lowest flow rate which persists for seven days at least once every ten years. Lower flow rates occur for shorter periods than 7 days. Lower flow rates would result in higher in-stream TCDD and TCDF concentrations for short periods. High TCDD concentrations for short periods are relevant because such short exposures have been shown to produce lethal effects in fish.

Since definitive chronic toxicity values are not available for TCDD and TCDF effects on aquatic species, especially fish, chronic toxicity values were estimated from the test results of a 56-day study with TCDD on rainbow trout. Since the lowest test concentration (38 pg/L) caused 45 percent mortality, a chronic toxicity value for TCDD was estimated by dividing by a factor of 1000 (i.e., 0.038 pg/L). Selection of an estimation factor of 1000 was suggested by the Office of Water, because it has used values of that magnitude for certain chemicals when chronic toxicity data were unavailable. OTS also uses a factor of 1000 to predict the chronic toxicity of a substance from a single LC50 value in the section 5 Premanufacturing Notice process under TSCA. The OTS factor of 1000 does not include any safety factor. Rather the factor of 1000 consists of a series of intervals with average factors of 10. Included in the three factors of 10 are: 1) a range of differences in species sensitivity; 2) an acute to chronic toxicity (i.e., LC50 to the maximum acceptable toxicant concentration (MATC) value); and 3) the differences in field-to-laboratory toxic effects. Given the fact that the LC50 value for TCDD could be lower than 38 pg/L for fish, a 1000 factor is not a conservative estimate for chronic toxicity.

1. Pulp Mill Effluent Risks to Fish

Aquatic risks were determined by a comparison of the chronic toxicity estimates for TCDD and TCDF with the in-stream concentrations predicted using the 7Q10 low flow rates for the section of river near each mill site. The Office of Water risk assessment concluded that the water column concentrations of TCDD and TCDF immediately downstream of 87 mills are estimated to exceed the predicted chronic toxicity values for at least 90 percent (78 mills) and 75 percent (65 mills) of the sites, respectively. The exposures could be higher, if estimates of in-stream concentrations by the Office of Water did not address multiple effluents into a water body from nearby pulp mills. Table 3 shows the percentage of pulp mills where in-stream concentrations of TCDD and/or TCDF are predicted to exceed the estimated lethal level for fish. Lethality in fish is predicted from TCDD exposures (± 1 ppq) immediately downstream of 65 percent of the 55 mills located on streams and rivers with untreated effluents and at 2 out of five pulp mills where the effluent has received POTW treatment. When additive toxicity for only TCDD and TCDF are considered (excluding other chlorinated organic compounds), 69 percent of the pulp mills on streams and rivers exceed lethal levels and 16 percent exceed the LC50. Adverse effects have been reported in receiving waters of some pulp mills. For example, the fish found in the Pigeon River downstream from a large paper mill on the the North Carolina/Tennessee border are in visibly bad health; many fish are eyeless and suffer from skin lesions on their bodies (Anon, 1990). While TCDD causes lesions, it is uncertain whether these effects are specifically due to TCDD or TCDF. The effects do, however, appear to be related to effluents from the pulp mill.

Migratory fish populations also may be at risk after passing through in-stream concentrations of TCDD and TCDF in contaminated segments of rivers, streams, and lakes. Exposure durations as short as 6 hours to TCDD have been studied and lethality observed several days thereafter. Consequently, death may occur in fish, even though an exposure was for only a few hours while passing through contaminated segments. It is uncertain if toxic effects would occur subsequent to spawning or affect the offspring of migratory fish species. For some migratory fish, like salmon on the Pacific Coast, which usually don't feed during migration and die shortly after swimming upstream and spawning, the exposure may have limited impact on the adults. But for other migratory species like the Atlantic salmon, sturgeon, striped bass, shad, herring, and smelt, which spawn more than one season, adverse effects on adult populations might be anticipated. Adverse effects may be expected for fry of all migratory species moving downstream through effluent discharges. The young of some migratory species, like salmon, remain in freshwater for one or two years before migrating to the sea. Adverse effects might be anticipated in these young and other nonmigratory species, which may reside in contaminated areas downstream of discharge areas.

Some waters in the U.S. are particularly vulnerable to the introduction of toxic pollutants. TCDD and TCDF have been identified as pollutants of concern in fish and wildlife in the Great Lakes (International Joint Commission, 1990). At least six of the 104 pulp mills have been identified as located on the Great Lakes and another two mills which are located on rivers that flow into the lakes. The TCDD and TCDF inputs into the Great Lakes from the effluents of these mills and the atmospheric transport from the numerous mills and incinerators upwind of these lakes are matters of concern. The cold, clear water and great depths in the Great Lakes accentuate the persistence of pollutants and the probable entry of such chemicals into the food web. With the flushing rates in the Great Lakes ranging from 27 years for Lake Erie to 183 years for Lake Superior, pollutants will remain in the lakes for long periods. The Great Lakes are economically important for sports fishing and commercial fisheries. TCDD and other coplanar PCBs have been implicated in the poor reproduction of resident populations of lake trout and chinook salmon in the Great Lakes in the past years (Ankley, 1989). Since many chemicals were found in fish samples, it is not clear which pollutant or what combination of chemicals are responsible for the reproductive decline. It is difficult to attribute fish population reductions to TCDD, because tissue levels of TCDD can not be correlated to lethality or reproductive failure, as shown by deaths during the depuration phase of BCF tests. Also, the level of detection for TCDD at 10 ppq in water is two to three orders of magnitude higher than the estimated chronic toxicity level. Reductions in important fish populations and hazardous contamination levels in the fish would adversely affect the economic value of these lakes for commercial and sport fisheries. Highly contaminated fish in the Great Lakes could pose a human health problem to people who consume fish from the Great Lakes. Accumulation of high TCDD levels in Great Lakes fish could result in a ban on commercial fishing and advisory recommendations for catch-and-release fishing only.

2. Effluent Risks to Aquatic Plants and Herbivores

Physical properties of TCDD and TCDF, such as low water solubility and high log P, are associated with chemicals which are expected to sorb to organic material. The sorption of TCDD and TCDF to suspended matter, plants, and sediments in an aquatic environment may pose a potential risk to plants, herbivores and benthic organisms. No toxic effects on plants were identified for TCDD. While active uptake via systemic root absorption is not expected to yield much TCDD in plants, TCDD is likely to sorb to organic surfaces of plants immediately downstream of pulp mills. The amounts of TCDD and TCDF that would adsorb to plants has not been estimated, nor have samples been taken for measurement.

The question of risks to herbivores, however, is not unimportant. For example, the West Indian manatee, an endangered species, has been at the center of discussions among EPA, USDI, and the Georgia Environmental Protection Division at a pulp mill discharge point located on the North River, a tributary of St. Mary's River in Camden County, Georgia (Endangered Species Technical Bulletin XIV (9-10) page 7). The discharge water from the pulp mill provides the warm water necessary for the manatees to survive the winter without migrating south to warm springs on the St. Johns River in Florida. Dermal exposure to dioxins and consumption of TCDD-contaminated plants pose likely routes of exposure which might produce lethal or sublethal effects. If exposure levels in plants and dermal uptake can be measured or estimated, potential adverse effects on the endangered manatee and other aquatic herbivores should be considered further.

3. Effluent Risks to Benthic Organisms

Sediments downstream of effluent discharges from pulp mills are predicted to be contaminated by dioxins and furans. If the half-life in sediments are similar to the 10 to 15 years in soils for TCDD, the dioxin- and furan-contaminated sediments may pose a problem for many years. The extent of the contaminated sediments produced from pulp mill discharges were not determined by monitoring or modelling. At these soil degradation rates, in ten years TCDD levels in sediments would be more than 7 times higher than the annual deposition levels. Risks to benthic species can not be determined at this time, because sediment toxicity data on TCDD are not available for benthic species. Also, concentrations of TCDD and TCDF in sediments are not available for the 104 pulp mills.

However, TCDD concentrations have been measured in the sediments in the Fox River, Wisconsin; the mean TCDD level for 13 sites was 3.1 pg/g (pptr) and ranged from undetected at 1.4 pg/g to 7.4 pg/g (Ankley *et al*., in press). The TCDF levels at the same sites average 7.6 times higher than TCDD and ranged from 0.1 to 61.1 pg/g. The highest TCDD and TCDF concentrations were found at the site of the pulp mill for U.S. Paper. The numbers of benthic fauna were significantly reduced at the pulp mill site compared to the control site. The average number of chironomids and oligochaetes at the pulp mill site were significantly lower than the controls. Numbers of organisms in both taxa were less than 1 percent of the control levels. The numbers of benthic fauna were also significantly reduced at all 9 sites downstream of the pulp mill. Other pollutants measured at the sites included penta, hexa, hepta, and octa forms of dioxin and furans. Adverse effects of pulp mill effluents on endangered benthic populations should be considered, especially for several endangered freshwater mussel species located in the Mississippi, Ohio, and other rivers where pulp mill effluent is discharged.

The contaminated sediments can also be expected to provide a reservoir from which dioxins and furans will enter the food web and be bioaccumulated by benthic organisms and bottom feeders, such as carp, catfish, and other edible fish species. Dioxins and furans are expected to be transferred from one trophic level to another. Toxic effects might be anticipated in those TCDD-sensitive species throughout the food web, especially in the top carnivores such as salmon, bass, pike, greyling, and fish-eating birds and mammals, including humans.

4. Effluent Risks to Fish-eating Birds and Mammals

In addition to sediments, chlorinated dioxins and furans can also bioconcentrate in aquatic organisms to levels several orders of magnitude higher than the levels found in the water column. TCDD bioconcentration factors have been reported to range from 5,800 to over 100,000 times the water concentrations (Table 2). The lower BCF values reflect shorter exposure durations where dioxin levels in the fish have not yet attained steady-state equilibrium with the concentrations in the water. Bioconcentration from water and bioaccumulation by benthic organisms are two routes of uptake by which TCDD and TCDF can enter into the food web. Studies on some other persistent chemicals indicate that together the two sources can produce slightly higher concentrations in fish than by one or the other route of exposure. The greatest effects for chemicals that accumulate in a food web tend to focus on those species that are the top predatory fish, birds, and mammals.

The list of birds and mammals that feed on fish and other aquatic organisms is extensive. The list includes many wildlife species that are deemed valuable for aesthetic or recreational reasons. In the past some wildlife species were found to be indicators by which we could measure the health of aquatic environments. Wildlife that could be at risk, if they feed on aquatic organisms in contaminated areas, include some federally-listed endangered (E) and threatened (T) species. A partial list of aquatic-feeding birds which could potentially be at risk would include the bald eagle (E), osprey, brown pelican (E), egrets, herons, ibises, spoonbills, Mississippi sandhill crane (E), wood storks (E), whooping cranes (E), piping plovers (E), cormorants, ducks, geese, gulls, etc..

Some avian species feed in open waters, while other species feed along the shoreline or shallow water. The composition of aquatic bird diets vary widely and are dependent on the species and its local. Some birds feed primarily on fish, such as the bald eagle, the osprey, and brown pelican. Other species, like the egrets, cranes, and herons, prey on fish, crustacea, amphibians, etc.. Spoonbills, ibises, piping plovers, and sandpipers probe the sediments for benthic organisms.

A large number of mammalian species also feed on fish and other aquatic organisms, including grizzly bears (E), black bears, mink, river otters, raccoons, opossums, foxes, sea otters, wolves, wolverine, etc.. With the exception of the river otter and sea otter, some mammals feed on aquatic organisms only at certain periods such as during fish migrations and as opportunistic finds. Consequently, risk assessment for most mammalian species is complicated by how often they might feed on dioxin-contaminated aquatic organisms.

Even though the proximity of wildlife to pulp mills has not yet been clearly determined, some data are available from which risks can be estimated. Dietary exposure levels for birds and mammals to TCDD should be calculated on the prey's whole body concentrations, because these predators typically eat the whole organism. Therefore, wildlife are typically exposed to higher TCDD levels than humans who eat only the filet (normally the highest chemical levels are found in viscera and outer skin of fish and aquatic organisms). Even higher risks might be anticipated for birds (e.g., the bald eagle) and mammals that tend to feed mostly on the softer viscera which contain higher TCDD levels than predicted as the average TCDD body concentration in aquatic organisms. Although there is no correlation between TCDD levels in an organism and death, scavengers feeding on the carcasses of dead organisms may consume higher than average TCDD concentrations.

Wildlife that feed only on live prey might also be expected to consume higher TCDD levels than average, because the sublethal effects of chemicals frequently affect the behavior of their prey. Abnormal swimming and loss of avoidance behavior caused by sublethal effects typically make such prey more available to a predator than healthy prey. Therefore, risk assessments based on an average TCDD concentration may significantly underestimate the exposure to dioxin for some predators. Accumulation of TCDD by less sensitive fish, amphibian, and benthic species may reach higher concentrations and pose an even greater risk to predators.

The New York Department of Environmental Conservation (Newell, 1987) reviewed non-cancer toxicity data for dioxins for piscivorous mammals and birds and arrived at a dietary criterion for consumption of fish. They determined that wildlife feeding primarily on fish with a concentration of greater than 3 pptr TCDD were at risk. Comparison of that 3 pptr toxicity value with measured TCDD concentrations in whole fish (Table 4) sampled near pulp mills in the National Bioaccumulation Study indicates that 66 percent (57/86) of the fish samples exceeded that threshold toxicity value. Over 38 percent of the fish sampled (33/86) contained twice the dioxin level in the criterion. Distribution of whole fish contaminated with more than 3 pptr TCDD include 21 states from Florida to Minnesota and from Maine to California. The fish with low dioxin levels (i.e., less than 3 pptr) were usually collected from large bodies of water such as lakes and the Puget Sound area. The mean measured TCDD concentration in whole fish is about 7 pptr. Since only a single sample of whole fish was analyzed from each site, the range and distribution of TCDD concentrations in the fish at these sites can not be determined. Additional monitoring of fish and aquatic organisms for TCDD and TCDF was conducted at 39 selected sites in Arkansas, Louisiana, and Texas (Crocker and Young, 1990). High TCDD levels in edible tissues were found at several sites. The highest concentrations of TCDD were found in fish from the Red River (41 pptr) and crabs from the Houston Ship Channel (55 pptr).

Measured TCDD levels in whole fish from several areas appear high enough to pose an unacceptable risk to resident wildlife species even with large feeding ranges. For example, if a bald eagle consumed only half of the fish from a contaminated area and that fish contained only 6 pptr TCDD, the risk would be the equivalent to an eagle feeding solely on fish with 3 pptr TCDD. In the area around the first 12 pulp mills in Table 4, wildlife would only have to eat only one-tenth of the fish or less from the receiving waters to be at risk. Those 12 pulp mills are widespread and are located in 10 different states.

In the Great Lakes area, the reproduction of herring gulls (Fox, 1989), and Forester's tern (Kubiak, 1989) populations have been significantly impaired. In the Fox River-Green Bay area, preliminary field studies downstream from chlorine-bleaching pulp mills also indicate apparent adverse reproductive effects in Forester's terns and red-winged blackbirds (Ankley et al., in press). Again, many pollutants are present in the sediments and it is not certain which or what chemical(s) are responsible for these adverse effects. Toxic responses in the tern embryos are consistent with toxic responses associated with TCDD and PCBs. Given similar uptake rates from sediments as soils (3.5 times the 7.4 pg/g in sediments), benthic organisms in the Fox River adjacent to U.S. Paper would contain about 26 pptr TCDD or 8 times the NY DEC chronic dietary criteria of 3 pptr for mammals and birds.

B. Terrestrial Risk Assessment for Land Application of TCDD- and TCDF-contaminated Sludge

1. Evaluation of the Abt Model

The Abt model estimates risks to wildlife from TCDD and TCDF from bioaccumalation and food web exposures following application of pulp mill sludges to forested areas. The methods used in the Abt model were reasonable and the assumptions appear to be realistic using moderate parameter values. Comparison of the modelling estimates of TCDD in soil and earthworms with measured concentrations in the Wisconsin study indicated very similar TCDD and TCDF concentrations. The prediction of adverse effects in birds in the Abt report appear to be supported by the elevated enzyme levels showing sublethal effects in robins in the

Wisconsin study. Subsequent field data from Wisconsin indicate reduced viability in robin embryos in areas treated with pulp sludge.

2. Evaluation of the NCASI Study in Wisconsin

The report by the National Council of the Paper Industry for Air and Stream Improvement, Inc. (NCASI, 1987 unpublished) contains information from a Wisconsin study on sludge-treated red pine plantations. The measured concentrations of TCDD and TCDF in soil, earthworms, and deer mice were useful in a comparison with the estimates by Abt. Despite the NCASI claims that no statistically significant adverse effects were found resulting from sludge treatment of the red pines, some significant differences were reported between sludge-treated and control areas. Most significant differences indicated higher populations in the treated areas for deer mice and earthworms. Treatment of the pines with pulp sludge altered the environment by increasing the moisture content of the soil and the level of organic matter. Under more favorable conditions, faunal changes are reflected in higher numbers of soil organisms such as the earthworms and some mite species. Abundance of these prey populations attracted more predators (i.e., deer mice). Toxic effects, if any, are obscured as mice from surrounding areas immigrate into an environment that is preferable habitat to surrounding areas.

Species diversity of soil organisms and vegetative cover were significantly higher in the controls than in sludge-treated areas. The number of available nests and observations were insufficient to evaluate the effects on bird reproduction. Some adverse effects on birds were indicated by elevated xenobiotic-metabolizing enzyme levels in robins collected from sludge-treated areas. Some results which suggest adverse effects were not statisically analyzed. For example, controls had greater diversity of small mammalian species (i.e, 5 versus 3 species); controls also had higher numbers of small mammals other than deer mice. Reported results from the Wisconsin study are summarized in Table 5.

The State of Wisconsin reviewed the study and required that an additional study be made. According to Dan Boardman of the Wisconsin Department of Natural Resources, North Central District Waste and Water Section (personal communication, 1990), Consolidated Paper voluntarily stopped application of pulp mill sludge to forested areas when adverse affects on wildlife were identified in field studies. Monitoring data showed adverse effects on embryo viability in robins inhabiting treated forest areas in Wisconsin. Wisconsin is on the lower end of predicted TCDD concentrations in soil for the seven states which practiced land application of pulp mill sludge (discussion in the following paragraph).

3. Comparison of the Abt Estimates with NCASI Data

The dioxin concentrations used by Abt in the terrestrial risk assessment were compared to available monitoring data from the Wisconsin study of pulp mill sludge applied to forested areas. The measured dioxin levels reported in the study are comparable with the estimates for Wisconsin. However, estimates of soil TCDD concentrations in Wisconsin are on the lower end of the scale of TCDD estimates in the seven states where sludge has been applied to land (Table 6). Exposure levels for TCDD and TCDF to wildlife cited for the seven states ranged from 0.2 to 181 pptr and from 0 to 795 pptr, respectively. With the exception of Pennsylvannia and Maine, the other states have higher estimated TCDD concentrations in soil than Wisconsin. Consequently, the indications of adverse effects to diversity and birds found in Wisconsin could be higher in the other states.

4. Potential Effects of Land Application on Endangered Species

The potential for an exposure of endangered and threatened species to TCDD/TCDF was considered for land application of pulp mill sludge. Exposure was limited to only those counties where the seven mills were located that used land application of pulp sludges. A preliminary search of the EPA, Office of Pesticide Program files was made to determine which, if any, endangered or threatened species were located in those seven counties. A total of 15 species were identified from the seven counties (Table 7). No effort was made to determine the risk to any species or the likelihood of there exposure. TCDD exposure and risk to some of those species is considered unlikely. For instance, the three endangered sea turtles may enter the county only to nest on the sandy beaches. Additional endangered species might be added to the list, if application to land were to occur in adjacent counties.

III. Conclusions on Risk

The in-stream concentration estimates in receiving waters from about 90 percent of pulp and paper mill effluents exceed the estimated chronic toxicity value for TCDD to aquatic organisms (Tetra Tech, Inc., unpublished). Exposure to TCDD for even a short period may cause mortality in fish. Thus risks to migratory fish species are a concern if they must traverse TCDD-contaminated stretches of water.

Sediment toxicity data are not available for TCDD, but some risk to benthic organisms might be expected. Uptake by benthic organisms is a potentially important source of TCDD in the food web. Contaminated sediments also act as a long term source of TCDD for the aquatic system.

TCDD levels measured in whole fish collected near pulp and paper mill discharges in the National Bioaccumulation study indicate that 66 percent of the fish contain TCDD levels greater than 3 pptr, which is considered a risk to fish-eating birds and mammals. Levels in fish at some locations are so high that only a fraction of the diet from that area would be necessary to pose unacceptable risks to wildlife.

Land application of TCDD and TCDF-contaminated sludge from pulp and paper mills may pose a risk to terrestrial wildlife and possibly aquatic organisms. The level of risk is a function of levels of TCDD contamination, the amount of sludge applied, and the method of application. Risks to wildlife were predicted in six out of the seven states permitting land application. The modelled estimates of TCDD and TCDF concentrations were confirmed by measured concentrations in soil and earthworms in Wisconsin study. The initial Wisconsin study indicated possible adverse effects on wildlife, especially elevated enzyme levels in robins which indicate exposure to toxic chemicals, possibly TCDD or TCDF. Later monitoring data showed reduced embryo viability in robins in treated areas and land application of pulp mill sludge was stopped in Wisconsin.

Additional toxicity testing is needed to determine the no-observed-effect concentrations (NOEC) for TCDD chronic toxicity to fish, birds, and benthic organisms. A full-life fish toxicity test is needed to determine the NOEC for fish reproduction when TCDD deposition in fish eggs is a biological concern. An avian reproduction test is needed to address concerns for eggshell thinning which was identified in robins in the Wisconsin study. Since TCDD formation is not a linear function of chlorine levels, monitoring data are needed to determine the altered levels of TCDD and TCDF present in effluents and sludges. As the levels of TCDD and TCDF in effluents decrease, it is expected that their levels in sludge will increase. Data are needed on the levels of TCDD and TCDF entering the Great Lakes by atmospheric transport. Measurement of volatilization of TCDD and TCDF during the bleaching process, from effluents, and from pulp sludge are also needed to determine if they are released into the atmosphere.

Limitations of analytical methods for TCDD pose technical problems. The limit of detection for TCDD in water is 10 ppq, while the projected NOEC for fish is estimated to be about 0.038 ppq. The difference between technology and toxicity is almost 1000 times. With this analytical limitation, it is unlikely that in-stream chemical analyses will be possible at the NOEC. Analyses at some point in the pulping process has been proposed as an alternative, but the rate of dilution would have to be 1000 times or more for in-stream TCDD concentrations to be below the NOEC. Also, the in-stream concentrations would need to be sufficiently low that TCDD would not bioaccumulate enough to pose a risk to fish-eating birds and wildlife.

Some pulp and paper mills are located within the drainage area for the Great Lakes, which are ecologically and economically important. The long residence time of chemicals in the Great Lakes poses a problem for bioaccumulating chemicals. Also, some endangered species have been identified within the seven counties where pulp mill sludges are applied to land. If not properly managed, the landfilling of TCDD-contaminated sludges may pose a problem to aquatic organisms from runoff. The presence of endangered species in receiving waters or feeding near pulp mills have not yet been determined.

IV. References

Abt Associates, Inc. Unpublished. Risk assessment for TCDD and TCDF in pulp and paper sludge. EPA, Office of Pesticides and Toxic Substances contract (August 28, 1989 draft).

Adams, W. J., G. M. De Graeve, T. D. Sabourin, J. D. Cooney, and G. M. Mosher. 1986. Toxicity and bioconcentration of 2,3,7,8-TCDD to fathead minnows (Pimephales promelas). Chemosphere 15(9-12):1503-1511.

Ankley, G.T., M. D. Balcer, L. T. Brooke, D. J. Call, A. R. Carlson, P. M. Cook. R. D. Johnson, R. G. Kreis, Jr., K. Lodge, and G. J. Niemi. In press. Integrated assessment of contaminated sediments in the lower Fox River and Green Bay, Wisconsin. Submitted to J. Great Lakes Research.

Ankley, G. T., D. E. Tillitt, and J. P. Giesy. 1989. Reproductive implications of coplanar PCBs in Lake Michigan chinook salmon: Determination of biological potency with the H-4-II-E hepatoma bioassay. Abstract in SETAC symposium on transboundary pollution. Tenth Annual SETAC Meeting. October 28 - November 2, 1989 in Toronto, Canada.

Anon. 1990. Paper mill reduces dioxin discharge. Potomac Basin Reporter 46(2).

Batterman, A. R., P. M. Cook, K. B. Lodge, D. B. Lothenbach, and B. C. Butterworth. 1989. Methodology used for a laboratory determination of relative contributions of water, sediment and food chain routes of uptake for 2,3,7,8-TCDD bioaccumulation by lake trout in Lake Ontario. Chemosphere 19(1-6):451-458.

Boardman, D. (Personal communication with William Rabert in OTS) Wisconsin Department of Natural Resources, North Central District, Waste Water Section, Rhinelander, WI. Telephone number (715) 369-8972.

Branson, D. R., I. T. Takahashi, W. M. Parker, and G. E. Blau. 1985. Bioconcentration kinetics of 2,3,7,8-tetrachlorodibenzo-p-dioxin in rainbow trout. Environ. Toxicol. Chem. 4(6):779-788.

Cook, P. M. (Unpublished). Review of draft risk assessment from paper mill discharges. U.S. E.P.A., Environ. Res. Lab., Duluth, Memoradum to G, H. Grubbs, U.S. E.P.A., Assessment & Watershed Protection Division (WH-553). (December 26, 1989).

Crocker, P. A. and C. Young. 1990. Tetrachlorodibenzo-p-dioxins and -dibenzofurans in edible fish tissue at selected sites in Arkansas, Louisiana and Texas. U.S. EPA, Region 6, Dallas, Texas. 14 pages and Appendices.

Eisler, R. 1986. Dioxin hazards to fish, wildlife, and invertebrates: A synoptic review. U.S.D.I., Fish and Wildlife Service, Biol. Rep. 85(1.8). 37 p.

Fox, G. A. 1989. Temporal and spatial variation in a battery of biomarkers in Great Lakes fish-eating birds in relation to known patterns of chemical contamination. Abstract in SETAC symposium on transboundary pollution. Tenth Annual SETAC Meeting. October 28 - November 2, 1989 in Toronto, Canada.

Hudson, R. H., R. K. Tucker, and M. A. Haegele. 1984. Handbook of toxicity of pesticides to wildlife. Second edition. U.S.D.I., Fish Wildl. Serv., Res. Publ. 153. 90 p.

International Joint Commission. 1990. Fifth biennial report on Great Lakes water quality. Part II. 58 p.

Kubiak, T. J., H. J. Harris, J. Trick, T. C. Erdman, T. R. Schwartz, D. L. Stalling, L. M. Smith, L. Sileo, and D. Doucherty. 1989. Microcontaminants and the reproductive impairment of the Forster's tern on Green Bay-Lake Michigan. Abstract in SETAC symposium on transboundary pollution. Tenth Annual SETAC Meeting. October 28 - November 2, 1989 in Toronto, Canada.

Mehrle, P. M., D. R. Buckler, E. E. Little, L. M. Smith, J. D. Petty, P. H. Peterman, D. L. Stalling, G. M. De Graeve, J. J. Coyle, and W. J. Adams. 1988. Toxicity and bioconcentration of 2,3,7,8-tetrachlorodibenzodioxin and 2,3,7,8-tetrachlorodibenzofuran in rainbow trout. Environ. Toxicol. Chem. 7(1):47-62.

National Council of the Paper Industry for Air and Stream Improvement, Inc. Unpublished. Land treatment effects on wildlife populations in red pine plantations. NCASI, Technical Bulletin No. 526 (June 1987).

Newell, A. J., D. W. Johnson, and L. K. Allen. 1987. Niagara River Biota Contamination Project: Fish flesh criteria for piscivorous wildlife. New York State, Department of Environmental Conservation Publication, Tech. Rep. 87-3. 182 p.

Tetra Tech, Inc. (Unpublished). Risk assessment for 2378-TCDD and 2378-TCDF contaminated receiving waters from U.S. chlorine-bleaching pulp and paper mills. Prepared for U.S. Environmental Protection Agency, Assessment and Watershed Protection Division, Washington, D.C. Contract No. 68-C9-0013, Work Assignment No. 1-13.

U.S. Environmental Protection Agency. 1989. Update of toxicity equivalent factors for estimating risks associated with exposures to mixtures of chlorinated dibenzo-p-dioxins and dibenzofurans (CDDs and CDFs). Draft report. Wash., D.C.

Table 1. Select environmental toxicity values reported for TCDD

Species	Exposure Duration	Endpoint Type	Toxicity Values	
Terrestrial Mammals				
Guinea pig	1 dose	LD50	0.6 - 2.5	ug/kg
Rats	1 dose	LD50	22 - 45	ug/kg
Rhesus monkey	1 dose	LD50	< 70	ug/kg
Mouse	1 dose	LD50	114 - 284	ug/kg
Rabbit	1 dose	LD50	155	ug/kg
Hamster	1 dose	LD50	1,157 - 5,051	ug/kg
Rat	Reprod.	LOAEL	10	ng/kg
Rhesus monkey	Reprod.	LOAEL	1.7	ng/kg
Birds				
Bobwhite quail	1 dose	LD50	15 *	ug/kg
Domestic chicken	1 dose	LD50	25 - 50	ug/kg
Mallard duck	1 dose	LD50	>> 108 *	ug/kg
Ringed turtle dove	1 dose	LD50	> 810 *	ug/kg
Leghorn chicken	21 days	NOEL	100	ng/kg
Bluebird (eggs)	Reprod.	LOAEL	65	pptr
Fish				
Rainbow trout	28 days	LC50	40	pg/L

* Regurgitation was reported for these tests; thus, toxicity may be less than the toxicity value suggests.
Bobwhite quail do not regurgitate; thus the LD50 may be accurate. Mallard ducks frequently regurgitate; thus the absence of effects may be do to limited exposure.
Ringed turtle-doves showed some toxic effects, but not enough to compute a LD50 value. Deaths occurred 13 to 37 days after treatment.

References:

Mammalian and acute avian data cited in Eisler (1986).
Avian chronic data cited in Abt report (unpublished).
Rainbow trout data reported by Mehrle *et al*. (1988).

Table 2. TCDD and TCDF bioconcentration factors estimated for various durations of exposure.

Species	Exposure	Measured BCF	Estimated BCF
TCDD:			
Rainbow trout a	6 hours	24 X	9,270 X
Rainbow trout b	28 days	26,707 X	37,000 - 86,000 X
Fathead minnow c	28 days	5,840 X	7,900 X
Fathead minnow d	71 days	----	97,000 - 159,000 X
Carp d	71 days	----	66,000 X
TCDF:			
Rainbow trout b	28 days	2,450 - 6,050 X	

References:

a Branson _et_ _al_. (1985)

b Mehrle _et_ _al_. (1988)

c Adams _et_ _al_. (1986)

d Cook (Unpublished).

Table 3. Revised estimates of percent sites with environmental concentrations exceeding the estimated lethal levels for TCDD (1 ppq), TCDF (10 ppq), and the TCDD/TCDF toxic eqivalents (TEQ).

Parameter	Number	TCDD	TCDF	TEQ
Group 1.	55			
Streams (7Q10)				
≥ 1 pg/L		65	-	69
≥ 10 pg/L		31	51	33
≥ 40 pg/L		11	-	16
≥100 pg/L		-	16	
≥400 pg/L		-	7	
Group 2.				
A. Open Water	6			
≥ 1 pg/L		67	-	83
≥ 10 pg/L		0	33	0
C. Post-treatment	2			
≥ 1 pg/L		50	-	50
≥ 10 pg/L		0	50	0
Group 4.				
Post-treatment	5			
≥ 1 pg/L		40	-	40
≥ 10 pg/L		20	40	20
Total	68			
≥ 1 pg/L		63	-	68
≥ 10 pg/L		26	49	28
≥ 40 pg/L		9	-	13
≥100 pg/L		-	13	
≥400 pg/L		-	6	

Based on Office of Water Estimates and excluding sites with no detectable levels or no dilution data

Table 4. Distribution of dioxin concentrations in whole fish sampled in the National Bioaccumulation Study

Dioxin Conc. (pptr)	Fish Species	State	Water Body
117.89	Carp	Louisiana	Wham Brake
107.02	Blue Catfish	South Carolina	Sampit River
75.70	Sucker	North Carolina	Pigeon River
67.18	Carp	Wisconsin	Wisconsin River
58.21	White sucker	Maryland	N. Br. Potomac River
40.96	Sucker	Maine	Androscoggin River
34.40	Catfish	Mississippi	Escatawpa River
33.86	Blue Catfish	Arkansas	Arkansas River
32.69	White sucker	Minnesota	Rainy River
30.04	Carp	Alabama	Coosa River
28.66	Carp	Alabama	Alabama River
24.04	Carp	Florida	Elevenmile Creek
24.01	Spot	Georgia	Turtle River
22.07	Carp	North Carolina	Pigeon River
21.01	Carp	Michigan	Menominee River
16.60	Sm. buffalo	Alabama	Chicasaw River
16.08	Sucker	Maine	Androscoggin River
15.31	Carp	South Carolina	Catawbee River
14.75	Channel catfish	Ohio	Scioto River
13.69	Channel catfish	Louisiana	Bayou Anacoco
13.19	Bowfin	Florida	Fenholloway River
9.10	Carp	South Carolina	Wateree River
8.58	Carp	Ohio	Scioto River
8.54	Carp	Wisconsin	Peshtigo River
7.97	White sucker	Maine	Penobscot River
7.87	Sucker	Massachusetts	Millers River
7.82	Sucker	New Hampshire	Androscoggin River
6.76	Shorthead redhorse	Virginia	James River
6.40	White sucker	Maine	Kennebec River
6.35	Sucker	California	Sacramento River
6.00	Carp	Mississippi	Mississippi River
5.79	White sucker	Pennsylvannia	Clarion River
5.23	Sucker	Washington	Columbia River
5.20	White sucker	Maine	Presumoscot River
5.12	Sucker	Washington	Columbia River
5.02	Wh carp	Wisconsin	Wisconsin River
4.88	Spotted sucker	Georgia	Altamana River
4.75	Carp	Kentucky	Mississippi River
4.73	Carp	Arkansas	Mississippi River
4.50	Carp	Georgia	Savannah River
4.42	Carpsucker	Kentucky	Ohio River

Table 4. (Cont.)

Dioxin Conc. (pptr)	Fish Species	State	Water Body
4.30	Carp	Alabama	Tombigbee River
4.17	Sucker	Arkansas	Red River
3.97	Carp	Tennessee	Hiwassee River
3.92	Carp	Wisconsin	Lake Superior Ashland Harbor
3.85	Carp	Michigan	Escanaba River
3.80	Carp	Alabama	Tombigbee River
3.80	Carp	Alabama	Alabama River
3.62	Carp	Arkansas	Ouachita River
3.50	Hardhead catfish	Florida	St. Josephs Bay
3.47	Sucker	California	San Joaquin River
3.46	Carp	Michigan	Muskegon River
3.13	Hardhead catfish	Florida	St. Andrew Bay
3.10	Carp	Alabama	Tombigbee River
2.78	Sucker	Oregon	Columbia River
2.40 nd	Carp	Wisconsin	Wisconsin River
2.01	Redhorse sucker	North Carolina	Neuse River
1.79	Flathead catfish	Louisiana	Mississippi River
1.71	White sucker	Penns.	Hoiter Creek
1.69	Carp	Georgia	Flint River/ Lake Blackshear
1.58	Catfish	Texas	Lake Sam Rayburn
1.57	St. flounder	Washington	Steamboat Slough
1.51	St. flounder	Washington	Commencement Bay
1.40 nd	Largescale sucker	Montana	Clark Fork River
1.20	Goldfish	New York	Hudson River
1.20 nd	Carp	Tennessee	Holston River
1.20 nd	Red drum	Georgia	North River
1.10 nd	Catfish	Virginia	Pamunkey River
1.11 nd	Atlanta salmon	Washington	Port Angeles Bay
1.10 nd	Flathead sole	Alaska	Ward Cove
1.00 nd	St. Flounder	Washington	Grays Harbor
0.90 nd	Flathead sole	Alaska	Silver Bay
0.76	Sucker	Oregon	Willamette River
0.70	Carp	Texas	Sulfur River
0.67 nd	White sucker	Maine	St. Croix River
0.59	Redhorse sucker	Pennsylvannia	Susquehanna River
0.55	Quillback carp	Alabama	Conecun River
0.50	White sucker	Minnesota	St. Louis River
0.46	Sucker	Idaho	Snake River
0.45	St. Flounder	Washington	Grays Harbor
0.41	Sm. Buffalo	Texas	Neches River

nd - not detected

Table 5. Data summary on results of sludge treatment in Wisconsin red pine plantation field study (NCASI, unpublished).

Species/Parameter	Treatment Mean (range)	Control Mean (range)	Sign. Diff.
Sludge			
Residues (pptr)			
TCDD	(53 - 128)		
TCDF	(280)		
Soil			
Residues (pptr)			
TCDD	10.8 (7 - 14)	ND ≥ 0.6	Yes
TCDF	106 (38 - 160)	ND ≥ 2.0	Yes
Residues (ug/m2)			
TCDD	0.35 (0.23 - 0.48)	ND ≥ 0.6	
TCDF	3.50 (1.20 - 5.50)	ND ≥ 2.0	
Moisture Content (percent)	24.2 (15.0 - 34.0)	11.9 (9.7- 15.9)	Yes
Litter Arthropods			
Density (Number/sample)	218 (34 - 524)	205 (131 - 299)	No
Diversity (taxa/plot)	12.0 (8 - 17)	10.4 (8 - 14)	No
Mite Genera	40	24	
Soil Invertebrates			
Diversity (taxa/plot)	2.8 (1 - 5)	3.8 (2 - 5)	NSA
Density (organisms/ft3)	7.5 (2.3 - 16.9)	20.9 (12.3 - 33.1)	Yes
Earthworm			
Biomass (g/m3)	16.8 (0.9 - 50.3)	3.0 (0.5 - 10.3)	Yes
Residues (pptr)			
TCDD	35.8 (25 - 43)	ND ≥ 13	Yes
BCF estimate	* 3.3 X		
Vegetation			
Total Species	39	45	NSA
Diversity	13.4 (4 - 17)	18.0 (11 - 25)	NSA
Percent Cover	2.1 (1.2 - 2.9)	6.7 (2.6 - 17.6)	Yes

Table 5. (cont.)

Species/Parameter	Sludge Treatment Mean (range)	Control Mean (range)	Sign. Diff.
Small mammals			
Diversity (species)	3	5	NSA
Population Est. (animals/2.8 H)	(11.4 - 39.9)	(13.0 - 24.2)	NSA
Deer Mouse			
Population Est. (animals/2.8 H)	(10.6 - 35.3)	(5.8 - 16.6)	Yes
Residues (pptr)			
TCDD	15.3 (ND - 44.0)	ND ≥ 2	Yes
TCDF	7.3 (ND - 11.0)	ND ≥ 2	No
BCF estimate			
TCDD	1.4 X		
TCDF	0.07 X		
Forest Birds			
Diversity (species)	15 (6 - 10)	22 (10 - 14)	NSA
Total Birds	104.3 (62 - 180)	123.3 (55 - 220)	NSA
Abundance (birds/plot visit)	3.0 (2.6- 3.4)	2.7 (1.7- 3.2)	No
American Robin			
Abundance (pairs/plot)	29	7	Yes
Liver enzyme levels -- elevated			Yes
House Wren (pairs by mid-June)			No
Chipping Sparrow (pairs/ 100 H)	260	178	

ND - Not detected at the limit of detection
NSA - Not statistically analyzed
* - BCF values in the literature suggest up to 10 times soil

Table 6. Summary of revised TCDD and TCDF concentrations cited in the terrestrial risk assessment document by Abt

State Use/Soil Incorporation (depth in dm)		Concentrations in Sludge/Soil TCDD Conc. (pptr)	TCDF Conc. (pptr)
Georgia			
Forest	2.5	220 / 181	610 / 501
Maine			
Forest	2.5	13 / 1	55 / 5
Maryland			
Mine	0	80 / 80	471 / 471
Mississippi			
Agriculture	15	681 / 14	0 / 0
Ohio			
Mine	0	145 / 145	795 / 795
Pennsylvania			
Agriculture	15	34 / 0.2	10 / 0.07
Wisconsin			
Forest	2.5	* 109 / 9	1300 / 106

TCDD and TCDF concentrations in sludge taken from data collected in 104 mill study.

TCDD and TCDF levels in soil calculated as dilution, if the sludge was incorporated into the soil to the specified depth.

* The Wisconsin red pine field study samples measured 53 and 128 pptr TCDD in sludge and averaged 10.8 pptr TCDD and 106 pptr TCDF in soil.

Table 7. Results of preliminary search for endangered (E) and threatened (T) species found in counties where the seven pulp and paper mills are located which apply dioxin- and furan-contaminated sludge to land.

Endangered and Threatened Species	States with Soil Application						
	GA	ME	MD	MS	OH	PA	WI
Mammals							
Indiana Bat (E)			P		P	P	
West Indian Manatee (E)	K						
Birds							
Bald Eagle (E)	K	K					K
Piping Plover (E)	K	K					
Wood Stork (E)	K						
Red-cockaded Woodpecker (E)				K			
Reptiles							
Eastern Indigo Snake (T)				P			
Gopher Tortoise (T)				K			
Kemp's Ridley Sea Turtle (E)	K						
Leatherback Sea Turtle (E)	P						
Loggerhead Sea Turtle (T)	K						
Fish							
Shortnose Sturgeon		K					
Invertebrates							
Iowa Pleistocene Snail (terrestial) (E)							P
Plants							
Harperalla (E)			K				
Small Whorled Pogonia (E)		K					

* Information dated October 26, 1989

P - Possibly present in county
K - Known present in county

Pulp Mill Sites:
Camden County, Georgia
Cumberland County, Maine
Allegany County, Maryland
Perry County, Mississippi
Ross County, Ohio
Wyoming County, Pennsylvania
Wood County, Wisconsin

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. EPA 560/5-90-013

2.

3. Recipient's Accession No.

4. Title and Subtitle Assessment of Risks from Exposure of Humans, Terrestrial and Avian Wildlife, and Aquatic Life to Dioxins and Furans from Disposal and Use of Sludge from Bleached Kraft and Sulfite Pulp and Paper Mills

5. Report Date 7/90

6.

7. Author(s) Kirk O'Neal, Susan Keane, Randi Zielinski, Pat Jennings, Priscilla Halloran, Greg Schweer, Bob Morcock, Bill Rabert

8. Performing Organization Rept. No.

9. Performing Organization Name and Address

Abt Associates, Inc.
55 Wheeler St.
Cambridge, MA 02138

10. Project/Task/Work Unit No. 3-02, 1-15

11. Contract(C) or Grant(G) No.

(C) EPA 68-02-4283
(G) EPA 68-D9-0169

12. Sponsoring Organization Name and Address

United States Environmental Protection Agency
Office of Toxic Substances and Office of Solid Waste
401 M St., SW
Washington, D.C. 20460

13. Type of Report & Period Covered Final Report

14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This report assesses potential risks from exposure of humans, terrestrial and avian wildlife, and aquatic life to dioxins and furans from disposal and use of sludge from bleached kraft and sulfite pulp and paper mills. Potential risks to humans as a result of disposal of bleached paper wastes were also assessed. Pulp and paper mill sludge management practices for which general population risks were assessed include landfilling, surface impoundment, land application and distribution and marketing.

Effects on terrestrial and avian wildlife were examined as a result of land application of pulp and paper mill sludge. Pathways of exposure considered for wildlife include direct ingestion of soil and ingestion of prey items that have bio-concentrated dioxins and furans. Effects on aquatic life from discharge of pulp and paper mill effluents were also addressed.

17. Document Analysis a. Descriptors

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group

18. Availability Statement

Distribution unlimited

19. Security Class (This Report) Unclassified

20. Security Class (This Page) Unclassified

21. No. of Pages 706

22. Price

(See ANSI-Z39.18) See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce